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Perspective

The Resilience of Indigenous Peoples to Environmental Change

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https://doi.org/10.1016/j.oneear.2020.05.014

Indigenous peoples globally have high exposure to environmental change and are often considered an "at-risk" population, although there is growing evidence of their resilience. In this Perspective, we examine the common factors affecting this resilience by illustrating how the interconnected roles of place, agency, institutions, collective action, Indigenous knowledge, and learning help Indigenous peoples to cope and adapt to environmental change. Relationships with place are particularly important in that they provide a foundation for belief systems, identity, knowledge, and livelihood practices that underlie mechanisms through which environmental change is experienced, understood, resisted, and responded to. Many Indigenous peoples also face significant vulnerabilities, whereby place dislocation due to land dispossession, resettlement, and landscape fragmentation has challenged the persistence of Indigenous knowledge systems and undermined Indigenous institutions, compounded by the speed of environmental change. These vulnerabilities are closely linked to colonization, globalization, and development patterns, underlying the importance of tackling these pervasive structural challenges.

Introduction

We now live in the Anthropocene, an era in which human actions have become the main driver of environmental change.[1] Climate change, biodiversity loss, land-use change, and ocean acidification are among the main challenges facing humanity, and converging evidence indicates that planetary boundaries in key natural systems might already have been crossed.[1,2] Such stresses challenge our ability to achieve and maintain the Sustainable Development Goals and have the potential for widespread social, cultural, economic, and health impacts.[3,4]

Research on global environmental change seeks to document, describe, explain, and predict environmental changes and understand factors that create resilience or vulnerability. The field has grown rapidly, and the importance of this work is widely acknowledged. More critical observers, however, have noted the absence of social scientists and humanities scholars in these debates and the dominant earth sciences framing.[5] One symptom of this framing is the suppression of the complex geographies of risk through concepts such as planetary boundaries, planetary health, safe operating spaces, and global tipping points.[6] Although there might only be "one Earth," resilience and vulnerability to environmental change differs widely at national to household levels, reflecting a variety of factors including age, class, gender, ethnicity, income, and livelihood, among others. As Ribot[7] cautions, vulnerability does not "fall from the sky;" it is socially constructed.

Indigenous peoples are frequently identified as a population susceptible to the effects of environmental change.[4,8] This framing of Indigenous peoples as being "at risk," however, is often detached from the diverse ways in which people interpret and respond to environmental change[9] and can be used to legitimize outside intervention and control.[10–12] A growing body of research illustrates that Indigenous peoples have significant resilience and are actively observing and adapting to change in a diversity of ways.[13] Yet this research remains fragmented in that most articles focus on specific populations, regions, and/or risks and few studies examine broader trends in understanding.

In this Perspective, we identify, characterize, and examine the common factors affecting resilience to environmental change among Indigenous peoples globally. We draw upon a systematic review of 227 peer-reviewed articles published over the last decade to analyze how local-level factors interact with the broader political ecology and political economy to determine how environmental change is experienced, understood, resisted, and responded to. Structuring our analysis by using a resilience framing, we also illustrate how populations can be both resilient and vulnerable at the same time and how this might vary for different social groups, over time, and to different stresses. In writing this paper we acknowledge that we are non-Indigenous academics who work within the epistemic community of global-change research; this positionality affects our analysis and interpretation of the literature. Details on the review procedures and literature reviewed are cataloged in Note S1 and Tables S1 and S2.

Indigenous Peoples and Environmental Change

The United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) refers to Indigenous peoples as a community

of peoples sharing inter-generational ancestry and cultural aspects with original (pre-colonial) occupants of ancestral lands in a specific region of the world and recognizes the need for respective peoples to have autonomy in defining themselves as Indigenous. At least 370 million people globally identify as Indigenous and manage and/or have tenure rights over at least a quarter of the world's land surface.[14] There are over an estimated 4,000 different languages spoken by Indigenous peoples,[15] reflecting the diverse cultures, worldviews, ways of knowing, and environments in which Indigenous peoples live. Across cultures, Indigenous peoples often share deep social, cultural, and spiritual ties to their "lands"—a term that captures Indigenous territories in general, including terrestrial, water, and associated spiritual environments—and their livelihoods, health, and well-being are closely linked to activities such as hunting, fishing, herding, foraging, small-scale farming, and land- and water-management practices that have developed over many generations.

Strong connections to the "land" held by many Indigenous peoples bring unique considerations for understanding and responding to environmental change. Thus, the indirect effects of environmental change on interpersonal and environmental relationships, life experience, spiritual considerations, family, kinship, and oral history are often as important as, if not more so, the more direct impacts of change. As stewards and guardians of lands that intersect with about 40% of all terrestrial protected areas and ecologically intact landscapes,[14] Indigenous peoples also have a central role in detecting and managing change. Other factors that affect how Indigenous peoples are affected by and respond to environmental change include habitation in areas undergoing rapid change, high levels of socioeconomic disadvantage, a greater burden of ill health, and political marginalization.[13,16] Even within the same region, these factors can create very different profiles of resilience and vulnerability between (and within) Indigenous peoples and other populations (e.g., Labbe et al.[17] and Donnelly et al.[18]).

Resilience Factors and Indigenous Peoples

The concept of resilience has been defined and used in various ways in the literature,[19] and we use it here to think holistically about the general characteristics that affect the "capacity of individuals, communities, and systems to survive, adapt, and grow in the face of stress and shocks, and even transform when conditions require it."[20] In doing so, we acknowledge the parallel concept of vulnerability, which seeks to understand the factors that create susceptibly to harm.[21–23] Resilience is a function of the combined result of coping, adaptive, and transformative capacities, which in turn lead to persistence, incremental adjustments, or transformational responses in the face of environmental change. In some cases, vulnerability emerges as a function of a deficit, absence, or weakening of coping, adaptive, and/or transformative capacities or reflects such capacities as being exceeded by the magnitude of changing conditions; that is, vulnerability is sometimes the flip side of resilience. Yet vulnerability is not always simply the opposite of resilience, and both can exist simultaneously within a population and vary among social groups, over time, and by the nature of stress(ors).[24] Thus, factors creating resilience for some might equally create vulnerability for others.

We use a resilience framing to capture the interactions between human and natural systems that determine the implications of environmental change, including processes and feedbacks at various scales, although we note that such a focus does not *a priori* establish human systems as resilient and can also focus analysis on vulnerabilities. There is widespread debate on the strengths and weaknesses of the concept of resilience, which is covered elsewhere (e.g., Kelman et al.[21] and Bene et al.[25,26]). The factors affecting resilience to environmental change will be determined by livelihood conditions and social, cultural, economic, demographic, and political factors operating over various spatial-temporal scales.[20,26] These broader influences provide the context within which local-level factors or "place-based elements" operate to affect resilience.[27,28] Using a modified version of Galappaththi et al.'s framework[27,29,30]—which was developed through an iterative approach based on a review of the literature on determinants of resilience and fieldwork with Indigenous communities in the Global North and South—we focus on how a network of place-based elements affect the resilience of Indigenous peoples to environmental change by focusing on the role of place, agency, institutions, collective action, Indigenous knowledge (IK), and learning. Varying by context, these elements interact dynamically with each other to create different levels of resilience or vulnerability among individuals, households, and communities. They are also interconnected with coping,[31,32] adaptive, and transformative capacities through learning, feedback, and self-organization or reorganization.[33] Through learning and collective action, for example, coping mechanisms employed to deal with environmental change can become adaptive if they feedback to change behavior, institutions, and risk perceptions, among other factors, through adaptive learning and can become transformative if they lead to fundamental shifts in system function (e.g., altered power structures).

Place

Place broadly refers to spaces that have acquired meaning for those associated with them. It captures the nature of the environment to which individuals or cultural groups have attachment to and contexts that give meaning and value to people's lives.[34] Deep links between Indigenous peoples and place are documented in diverse contexts globally,[35] often forming the foundation of cultural belief systems. In many Indigenous cultures, nature is referred to in interpersonal terms where there is no separation between the human and non-human world, and for some, nature is viewed as a sentient being capable of reciprocity, collaboration, and/or harm.[36–38] This closeness and intimacy to place promotes resilience to environmental change, thus underpinning moral relationships of responsibility to protect and care for nature (e.g., through habitat protection, sacred sites, access rules, and species conservation), helping to reduce the effects of environmental change, and minimizing environmental pressure (e.g., by preventing deforestation and creating species-rich habitat). Research in Canada and Australia has shown associations between connection to place and improved health outcomes, which has been described to give people the strength to tackle changes being observed.[39,40]

Although the centrality of place in Indigenous cultures provides strength and wellness, it can also create susceptibility to disruptions caused by environmental change. Strong emotional

reactions leading to ecological grief have been documented among Inuit, for example, because changing ice and weather regimes reduce access to traditional hunting and fishing locations,[35,41] whereas some Inuit communities are transforming from land-based (e.g., caribou) to aquatic-based livelihoods to build climate resilience.[42] In these instances, environmental change becomes direct and personal, disrupting cultural practices, social cohesion, and belief systems and compounding the effects of place disruption caused by land dispossession. Strong place attachment and reliance on a narrow resource base and/or a limited availability of culturally important resources can also put communities at constant threat of environmental change and limit the potential for adaptations through relocation or changing livelihoods,[43,44] although in many contexts such limits stem as much from colonially imposed constraints to traditional mobility patterns as they do from environmental change.[45]

Although place attachment has the potential to create vulnerability, "place" is not static, and new configurations of people-place relationships often reflect changing socio-ecological conditions. Place thus remains an enduring feature in many Indigenous cultures. Among Indigenous peoples of Ka'ūpūlehu, Hawaii, McMillen et al.[46] describe how, despite dramatic changes in livelihoods away from traditional subsistence activities, strong place relationships have been maintained through stewardship and educational activities. Attachment to multiple places has also been a central feature of Indigenous resource-management strategies, particularly in regions sensitive to environmental change (e.g., Arctic and desert environments), such that mobility and flexibility enable the use of diverse environments to sustain the symbolic, cultural, and livelihood roles of place during periods of change. Working in Australia, for example, Zander et al.[47] note how the Yolngu peoples historically traveled extensively to secure essential resources in light of environmental stress, underpinning present-day willingness to consider temporary relocation in light of climate-change impacts. Such flexibility, however, is often circumscribed by the historical context of colonization, including forced resettlement, land dispossession, and landscape fragmentation, even in nations where Indigenous peoples have exercised some degree of self-determination (e.g., Sámi reindeer herders in Scandinavia).[48,49] In nations where Indigenous rights are not recognized or protected, loss of place can have profound implications for health, well-being, and vulnerability to environmental change.[50]

Agency

Agency concerns the ability of people, individually or collectively, to have choice in responding to environmental change and depends on people's belief that they can manage and control events that affect them as well as socio-economic and political conditions that enable them to take action.[28,51] Three narratives on the role of agency in affecting resilience to environmental change are discernible in the literature. These narratives are not necessarily mutually exclusive, such that differential agency is sometimes evident among individuals and communities.

One narrative contends that agency is high and underpins significant resilience. Studies here illustrate how agency stems from Indigenous socio-cultural organization where risk is managed through diversity and flexibility in resource use and habitation and where self-reliance, local decision-making power, and knowledge of managing environmental change support adaptation to changing conditions.[52–54] Working with a Canadian First Nations community, for example, Abu and Reed[55] use Levi-Strauss's concept of bricolage to argue that the process of "making do" with whatever is at hand allows Indigenous communities living in fragile ecosystems to innovate and improvise in the face of climate change. Similarly, working with Basotho of southern Africa, Palframan[56] finds the "anarchistic, improvisational nature" of traditional knowledge a key strength in responding to change and resisting outside control. Confidence in the ability to manage change has a powerful influence on agency and is described as important in a number of studies[52,57] in that it derives from perceptions of strength based on IK systems through which change is detected, a strong sense of place and community, and experience in dealing with past change.

Individual and community agency are often in tension with social, political, and economic structures and changes. A second narrative contends that these structures and changes are undermining the very socio-cultural organization upon which agency is based, embodied as a loss of decision-making control at local levels. Although globally there are increasing efforts to protect Indigenous rights, decisions on land use, development, and resource management continue to have limited input from Indigenous peoples, limiting agency to alter settlement patterns, resource management, and land use in response to environmental change.[57–59] Resistance to such outside control can strengthen agency, and a diversity of strategies described herein—including protests, resistance camps, refusal strategies, education programs, direct action, legal challenges, and calls for policy action, among others—are being used by Indigenous peoples globally. These actions can directly target environmental changes being observed, but more commonly they are articulated in the context of promoting self-determination, defending land rights, challenging power relations, and promoting justice. In the Peruvian Andes, for instance, Quechua peoples have confronted the impacts of colonization by creating the Potato Park to protect over 900 varieties of potato, reinvigorating cultural values of reciprocity, kinship, and solidarity that underpin community resilience.[60] In the Arctic, organizations such as the Inuit Circumpolar Council have used rapid climate change to draw attention to human rights violations, including by submitting a petition at the Inter-American Commission on Human Rights.[61] Yet, lack of control can equally reinforce feelings of powerlessness, particularly when people are faced with rapid change[62] and in cases where communities have already been dispossessed of their traditional lands.[50]

A third narrative focuses on how cultural beliefs can create risk attitudes that downplay agency, where change is viewed as inevitable and outside of human control. Studies in the Pacific Islands,[63,64] Caribbean,[43] and sub-Saharan Africa,[65] for example, illustrate a common perception that environmental change represents an "act of God" or represents the wrath of ancestors, whereby individuals can or should do little to avoid their fate beyond placing faith in divine intervention. In some Arctic Indigenous cultures, beliefs about the sentience of the natural world make thinking about the future in negative terms inappropriate.[61] Elsewhere, research illustrates how environmental change can be perceived as part of a cycle and as such does

not require specific action,[66,67] although experience with recurrent extremes in a climate-change context has been documented to change perceptions in some communities regarding the directional nature of change (e.g., Archer et al.[68]). Such cultural beliefs exert powerful influences on decision behavior but are not necessarily maladaptive, potentially supporting other resilience factors (e.g., collective action and IK),[69] although they can make proactive responses involving adaptation or transformation less culturally appropriate.

Institutions

Institutions are the formal and informal norms, rules, and organizations that stem from social interaction and guide behavior to help decide which actions are required, permitted, or forbidden.[70,71] Institutions are shaped by power relations and can imply different sets of obligations and actions according to age, gender, and livelihood, as well as effect resilience through multiple pathways.

Where Indigenous rights are recognized and/or significant decision-making power is locally held, customary laws and common property systems have been identified to promote sustainable resource use, contribute to the conservation of biodiversity, and reduce deforestation and land degradation. Herein, many traditional institutions have evolved to manage environmental stress. In the extreme environment of the Hindu Kush[72] and Sikkim Himalaya,[73] for example, village committees have instructed householders to restrict the number of animals kept and set dates for communal transhumance movements to help pastures recover from degradation and maintain resource buffers. Indigenous fire-management practices tied to key times during the seasonal calendar are common in Latin America and Australia, where such burning has been identified as reducing the occurrence of dangerous fires, increasing biodiversity, and enhancing carbon sinks.[74–76] In other areas, customary rules over marine and land tenure have been identified as providing mechanisms for dealing with resource variability and managing exposure to natural hazards. This includes spatial diversity of land holdings to minimize risk from extreme events,[77] the banning of logging in environmentally fragile areas,[69] and the placing of taboos on certain areas and resources to ensure recovery of the stocks in the face of stress (e.g., no fishing zones, sacred groves, and buffer areas).[77]

Institutions are embedded within IK systems, are closely linked to place, and are culturally internalized, produced, and reproduced by rituals, ceremonies, stories, and other traditions.[78] Within these institutions, strong leadership by chiefs, elders, and village councils and assemblies has been identified as being important in enforcing customary rules, conflict management, and collective planning and stewardship, enhancing the ability to manage environmental change.[53,77,79] These benefits aside, the emphasis on hierarchy and seniority in some cultures and contexts has been observed to limit adaptive capacity at the household level by constraining adaptation choices (e.g., mobility patterns) and can be exclusionary in patriarchal systems[63,77,80] (Table 1).

A key theme across articles reviewed is that Indigenous institutions are under threat. These trends are most prevalent in nations where Indigenous rights and sovereignty are not recognized or are poorly protected. In tropical forests of central Africa and Central America, for example, agricultural expansion, logging, the creation of nature reserves, and the promotion of scientific and state-led management practices have restricted or replaced Indigenous institutions.[50,83,84] For many Indigenous pastoralists, traditional institutions for managing risk through mobility and the joint ownership of assets and resources have been replaced by the privatization of land and enforcement of administrative boundaries, increasing vulnerability to environmental stress.[85] In the Pacific Islands, the disposition of native land has made people more vulnerable to drought impacts because they do not have the ability to relocate or diversify their agriculture.[54] Despite these trends, however, Indigenous institutions persist in many locations and have ebbed with changing circumstances, and there is evidence of revival and renewal in some regions (e.g., Eckert et al.[86]).

Collective Action

Collective action captures actions that a group of two or more people take together to meet a common goal.[27] Solidarity, communalism, loyalty, and fellowship are deeply rooted in many Indigenous belief systems—produced and reproduced through cultural practices—underpinning collective action. Collective action is closely linked to institutions but is also distinct, affecting resilience in multiple ways.

Firstly, cultural norms of sharing and reciprocity are important for risk management, risk sharing, and disaster recovery and vary by population (Table 1). Food sharing, for example, is highly valued in many Indigenous cultures and is critical for expanding the availability and diversity of food and providing a buffer during times of stress. Currenti et al.[63] describe how, among the iTaukei (Fiji), the custom of *kerekere* allows an individual to request a relative or neighbor for something they need with no expectation of repayment, and this practice has helped reduce the impacts of cyclones and flooding on vulnerable community members (e.g., the elderly). Sharing goes beyond material exchange and can also involve the provision of shelter,[87] social support and kinship,[88,89] the communal pooling of labor,[43,80] and information and knowledge[80,90] (Table 1). Regarding the latter, individuals with specialized knowledge and skill sets have been observed to develop in-depth understanding on the nature of environmental changes occurring, coping mechanisms, and adaptation options with associated responsibilities for ensuring that this knowledge is transmitted to inform behavior and decision making (e.g., closing fisheries [e.g., Hawaii][46] and altering land-use practices [e.g., the Arctic][91]). These responsibilities are grounded in the social nature of knowledge, which is viewed as being collectively held in many Indigenous cultures.

Secondly, collective action is important in promoting flexibility, shared leadership, and innovation in responding to environmental change. Customary laws might ascribe certain social practices or management responses to protect key resources, such as hunting and fishing regulations or restricted access. Particularly important for resilience in these instances are the processes through which such decisions are arrived at and through which different perspectives are reconciled, particularly given the difficult choices sometimes entailed in responding to environmental change. Apgar et al.[53] describe how, among the Guna in Panama, the cultural and spiritual framework of *Bab Igar* provides a basis for engaging and reconciling diverse viewpoints to enable adaptation and transformation to

Table 1. Examples of Pathways through which Beliefs, Rituals, and Values Underpin Collective Action, Influence Resilience, and Can Also Create Potential Vulnerabilities for Indigenous Peoples

Belief, Ritual, or Value	Indigenous Peoples	Nature of Collective Action	Resilience	Vulnerability	Reference
Rispek and *Kastom*	Nakanamanga, Vanuatu	socially accepted ways of behaving and relating to others on the basis of rank, status, kinship, and wider networks of exchange	–social cohesion facilitates planning and responding to climate hazards (e.g., maintaining communal water supply) –kinship helps with disaster recovery (shared labor and resources)	–patriarchal and hierarchical systems can exclude lower-status groups and women –regimented attitudes can act as barriers to the adoption of new adaptations (e.g., disease control)	Granderson[77]
Ayllu	Quechua in the "Potato Park," Peru	a social unit based on collectiveness and underpinned by common duties and obligations to family and territorial demarcation	–collective land stewardship (e.g., maintenance of traditional crop rotation) –collective organization of labor	–desire to scale up climate adaptation initiatives on the basis of cultural values of the Potato Park could increase vulnerability as more urbanized communities do not necessarily support or understand these values	Walshe and Argumedo[60]
Ubuntu	Xhosa, South Africa	local practice, custom, and tradition of communal living, ownership, support, and a high degree of loyalty to one another and structural foundation of self-perception	–underpins support systems (e.g., food sharing and communal labor) especially during weather-related disasters –strong belief that problems are solvable	–near-sighted future view such that solutions for climate change can be viewed as necessitating returning to the ways (behavior) of the past –climate change can be viewed as outside of local control	Apraku et al.,[81] Terblanche-Greeff et al.[82]
"Hand go, hand come"	Caribs, St. Vincent	informal community labor networks where one farmer assists another in cultivation or harvesting and would later be repaid in kind	–provides physical assistance (labor) and finance assistance for farmers to restore livelihoods after disasters (e.g., hurricanes)	–natural hazards can be viewed as acts of God, shaping decision making and behavior of individuals, which is largely non-adaptive prior to a hazard event	Smith and Rhiney[43]
War uet	Guna, Panama	ritual that enables collective reflection for transformative change, only engaged in times of crisis (e.g., disease epidemic); community is involved in an 8-day gathering to engage with the underlying cause of the disruption	–allows diversity of individual views to be expressed on response options –supports community cohesion	–none identified in the study	Apgar et al.[53]

socio-ecological change and thus build trust and unity in decision making. Here, ritual practice provides a safe space for different views to be expressed and for leaders of various "interest groups" to come together in collective decision-making forums. Leaders represent a web of interactions across communities and, importantly, change over time to allow for diversity. Gram-Hanssen[92] finds similar flexible and cohesive decision-making structures to enable proactive responses to environmental change in an Alaskan Yup'ik community.

Collective action does not always lead to resilience. Unequal power relationships in decision making and the prevalence of conservative attitudes have been noted to be exclusionary or restrictive in some instances (e.g., patriarchal systems) and might not be reflective of diverse interests.[64,77] Socio-cultural changes are also altering the processes and contexts through which collective action is produced and reproduced. This renders some practices potentially maladaptive, such as in urban Tuvalu, where cultural practices (e.g., prioritizing food quantity over food quality) have been observed to lower food security by dispersing limited resources and encouraging the consumption of cheap but nutrient-poor foods.[93] In other cases, shifts to a cash-based economy, more individualistic behavior, and state-led management have undermined kinship networks, where sharing can no longer be relied upon, and have reduced the authority of local decision-making structures.[77,94,95] Rapid environmental change presents an additional stress, potentially accelerating underling social trends. Among some Inuit communities, for example, sharing networks have been documented to be contracting as it becomes harder to procure traditional foods with climate impacts, in turn reducing familial connections on which collective action is based.[96,97] New forms of sharing and decision making, including the incorporation of cash into traditional economies,[96,98] new mechanisms of sharing (e.g., via Facebook),[99] and expansion of social networks to access external support,[66] have balanced some of these trends and are commonly documented where peoples have sovereignty over their territories. The ability of such reorganization for resilience to environmental change has not, however, been widely examined.

Indigenous Knowledge

IK refers to the understandings, skills, and philosophies developed by societies with long histories of interaction with their natural surroundings.[100] IK is rooted in inter-generational transmission of knowledge and oral history; is integral to cultural complexes, encompassing language, systems of classification, resource-use practices, social interactions, values, rituals, and spirituality; and has enabled societies to thrive and "live well" in a wide range of environments.[101–103] There is strong evidence across diverse contexts that IK is a major source of resilience in that it acts as a repository of accumulated experience and is closely linked to the other place-based elements through shaping belief systems.

Indigenous peoples hold many different types of environmental knowledge (e.g., climatological, botanical, ecological, and spiritual), helping them to detect, understand, and predict environmental change. Monitoring the status of the environment in terms of climatic conditions, habitats, species, and landscapes is often a common practice,[103,104] and knowledge is often devised into traditional seasonal calendars that use bioclimatic indicators to help make decisions about land use, harvesting, and mobility.[105,106] It is through such detailed observations and familiarity with local conditions, combined with social-ecological memory embodied in IK, that diverse Indigenous peoples globally have detected "unusual" changes in the environment.[107] Awareness that change is happening is essential for underpinning adaptation—dependent on the belief that change can be managed or controlled (i.e., agency)—and evidence from diverse contexts illustrates how repeated observations are constantly readjusting and updating traditional calendars and relationship cycles to reflect changes occurring, including in small island communities in Southeast Asia,[69] the Pacific Islands,[77] and African pastoral[105] and farming[106] communities.

IK guides resource-use and land-management practices, through which diversity and flexibility allow risk to be spread across space, time, assets, and community members, and has been demonstrated to be effective in managing environmental variability and change in studies from the Arctic to the Sahel. Diversity involves the widespread use of multiple species and different environments in Indigenous food systems, whereby food substitution allows people to cope with changes in the availability, access, and quality of food. In the Peruvian Amazon, for example, Zavaleta et al.,[95] working with the Shawi, describe how wild foods are a critical backup when flooding destroys crops by providing an important safety net. Diversity can also involve the use of different technologies and approaches for food production and processing.[37,108] Flexibility reflects the capacity to switch between strategies to manage stress and change and is closely linked to diversity and can involve strategies such as resource rotation, temporal restriction of harvest, and species protection. Indigenous herding systems typically emphasize flexibility over stability, whereby the size and composition of livestock holdings are altered in response to vegetation dynamics, livestock are moved according to the availability of water and pasture (e.g., seasonal migration), and livestock have evolved in environments characterized by high uncertainty and variation.[72,85,109] Subsistence hunting systems have similar flexibility, involving seasonal mobility cycles and opportunistic hunting of species based on availability,[108] and can involve the "resting" of certain locations to allow populations to recover.[79]

IK has also been observed to promote conservation and reduce environmental stress through the use of more species and landscape patches, reducing sensitivity to environmental changes.[86,110] Indigenous swidden cultivation-fallow management systems, for example, have been identified as resulting in more efficient forest management, lower-intensity use, and higher biodiversity than non-Indigenous management practices,[76] although they are often ignored in forest management.[84] In other areas, traditional construction methods and settlement planning have been identified as being more suited to local environmental conditions and more resistant to natural hazards (e.g., flooding, storms, and permafrost thaw).[63,111]

Many of these diverse strategies that underpin resilience can be broadly thought of as "indigenous mobility traditions."[45] Such mobility is often a central component of Indigenous institutions and political systems, integrates community norms and responsibilities, and is predicated upon in-depth knowledge of environmental conditions embodied within IK. The ability to switch food species in hunting societies, for example, depends

Table 2. Examples of Learning

Indigenous Peoples and Region	Learning Examples	Pathway to Resilience	Reference
Ka'ūpūlehu, Hawaii	as native tree populations have decreased, people look to widely distributed introduced species to signal the appropriate times to harvest sea urchins	development of new knowledge heuristics whereby community members have adapted knowledge transmission to suit the current context	McMillen et al.[46]
Konda Reddis, southern India	with reduced abundance of the historically important *jeelugu* tree, the *tati* tree has increasingly been adopted	altered livelihood practices, flexibility to change, and learning how to plant and use an alternative species have allowed communities to meet survival and cultural needs	Kodirekkala[121]
Coastal-Vedda, Sri Lanka	after facing three decades of war, Coastal-Vedda learned reservoir aquaculture techniques through local and stakeholder institutions (e.g., government and non-governmental organizations)	altered livelihood practices to face changing socio-ecological systems and moving from rice farming to reservoir aquaculture	Galappaththi et al.[30]
Inuit, Arctic Canada	young Inuit are inspired by technology and readily utilize it (e.g., the Internet), and Inuit co-learn through elders, learning by doing, and formal school education	co-learning opens more opportunities for building resilience in community fisheries to face rapid climatic challenges	Galappaththi et al.[29]

on knowledge of the behavior of different species and how they are harvested and prepared, confidence to travel in different environments, and the ability to synchronize activities in accordance with ecosystem dynamics.[79,104] Pastoralists depend on a rich ethno-botanical knowledge including awareness of the palatability of forage species for their different livestock types, behavioral patterns and seasonal habitat selection of their animals, and how these relate to short- to long-term environmental trajectories.[85,112] Yet, the dynamic transmission of IK is being threatened and Indigenous institutions are being undermined, as described above. In their systematic review of 92 articles focused on IK transmission, Aswani et al.[113] report that 77% of published articles document a loss of knowledge, and multiple studies from diverse regions document a weakening of traditional skills, knowledge, and their incomplete transmission to younger generations.[103,104,114] These trends reduce the capacity to detect, understand, and manage environmental change, undermining resilience, although they are being balanced in some regions by the incorporation of new knowledge and adaptive learning.

The erosion of IK reflects diverse and interconnected factors, including rapid environmental change, which can make some components of IK, including observational indicators and traditional forecasting, less reliable (however, see Learning).[46,115,116] More widely documented is the role of socio-cultural factors that are affecting how knowledge is acquired, maintained, transmitted, and utilized. Modernization processes, including increasing exposure to formal schooling, changing livelihoods, and market integration, for instance, have discouraged experiential learning, weakened traditional institutions, and reduced intergenerational communication.[95,103,104] Colonization and the associated loss of access to resources have undermined livelihoods, mobility, and the traditional practices through which risk is managed,[104,105] in turn affecting the rituals, beliefs, and relationships that sustain IK. For example, Pearce et al.[104] document how in the Arctic, forced settlement, Western schooling, and demographic change have reduced apprenticeship opportunities for young Inuit to acquire hunting skills, which has compromised the ability of youth to perform cultural roles associated with procuring and sharing traditional foods.

Learning

Learning reflects the capacity to generate, absorb, and process new information on changing conditions, assess response options, and frame or reframe problems.[28] Common to many Indigenous cultures, learning is experiential, whereby repeated and continued exposure and response to environmental conditions develop experience of how to manage them and enable response with learning. Learning is central to IK, whereby experimentation, practice, regular interaction, and openness to alteration underpin the continuous updating and re-examination of what is known in light of new observations and realities. This can involve integrating and adapting new practices and discarding old ones if they are no longer effective or adopting new technologies. The dynamic and pragmatic nature of IK challenges notions that IK is losing its relevance, and studies from the Arctic,[117,118] the Pacific Islands,[46,115] Australia,[88,119] sub-Saharan Africa,[106] and tropical forests[62,120] have documented how Indigenous peoples are continuously reclaiming, re-energizing, and rebuilding their knowledge systems in light of environmental change and other outside pressures. This can involve the development of new knowledge heuristics (e.g., new seasonal calendars), new livelihood strategies (e.g., altered cropping practices), the evolution of protocols of knowledge transmission, and the strengthening of traditional rituals and practices and can support rapid adaptation during times of change (Table 2). The importance of learning underpins Reyes-Garcia et al's[120] contention that Indigenous cultures are adaptive, although some researchers argue that the speed and non-linearity of environmental change are making learning increasingly difficult.[35,63]

The ability for learning to reduce vulnerability to environmental change depends on the opportunities available for learning, compatibility of worldviews to support learning, and socio-ecological memory. Elders, for example, play a key socio-cultural role in many Indigenous cultures by supporting learning

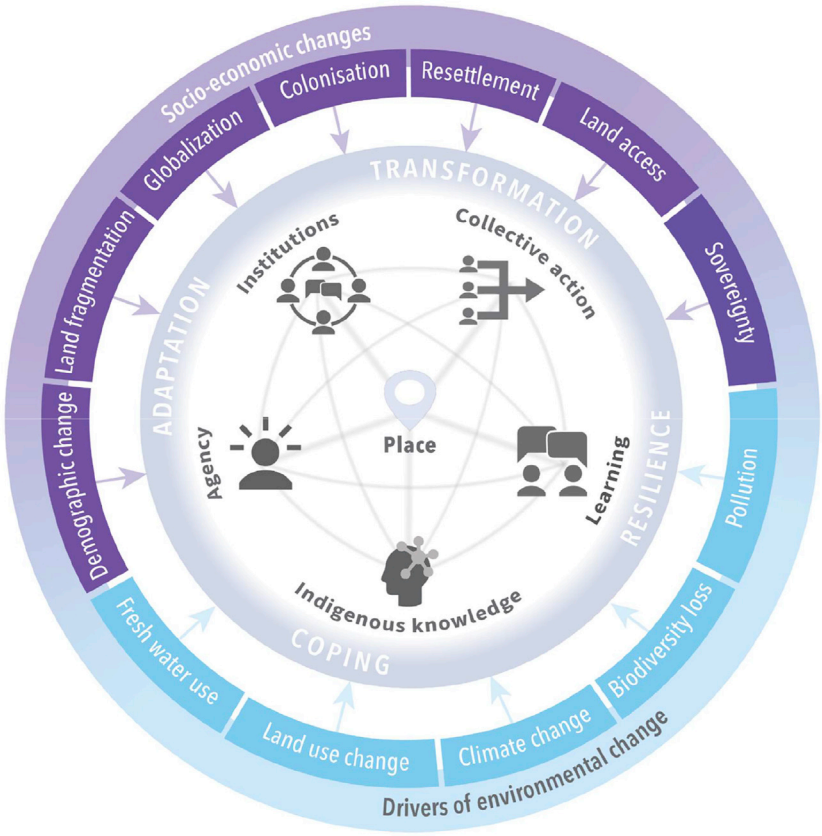

Figure 1. The Dynamic Interaction between Environmental and Human Factors in Shaping the Resilience of Indigenous Peoples to Environmental Change

processes through their extensive knowledge, experience, and memory. Population growth, loss of language, and changing cultural norms are making inter-generational communication more challenging, and elders can also promote conservative attitudes that resist change. A number of studies herein have documented what has been termed shifting baseline syndrome,[122] whereby reduced inter-generational knowledge transmission has compromised perceptions of what has changed or is changing, and this has implications for anticipating and adapting.[103] Opportunities for learning are also constrained in populations and communities who rely on a narrow resource base that is being undermined by the uncertainties and complexities inherent to environmental change. Among the Sakha in Siberia, where permafrost thaw is deteriorating pasture used for animal husbandry,[123] or Sámi reindeer herders, for whom unpredictability and extreme events are disrupting human-animal agency,[112] there are few opportunities in a contemporary setting for learning to occur.

Discussion

In this Perspective, we examine common factors affecting resilience to environmental change among Indigenous peoples. Given its global nature, we acknowledge the diversity of Indigenous livelihoods, cultures, and knowledge systems and the potential that this diversity might be lost in our global-scale review, although we note the breadth of the examined literature covering diverse regions and peoples (Note S2, Figures S1–S3, and Tables S3 and S4). The paper is particularly timely as the importance of Indigenous knowledge, voices, needs, and priorities is being articulated in a diversity of international forums, including policy processes established through the Paris Agreement, major UN assessments (including the Intergovernmental Panel on Climate Change and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services), and the Post-2020 Biodiversity Targets Task Force established through the UN Convention on Biological Diversity.[102,124]

Indigenous peoples globally are witnessing rapid environmental change. These changes are not experienced in isolation, however, but in the context of socio-cultural, economic, and political conditions and changes operating over different spatio-temporal scales. These factors shape how environmental change is experienced, understood, resisted, and responded to, and we illustrate how they operate to effect resilience by focusing on key place-based elements, each of which interacts with each other (Figure 1). Across diverse regions, we find numerous examples of resilience and evidence that Indigenous peoples are coping and adapting to rapid change. We also find examples of vulnerability and note that populations can be both resilient and vulnerable at the same time. Furthermore, many of the resilience factors we document are being undermined or challenged to varying degrees, differing by (and within) populations.

Far from being passive victims, Indigenous peoples are improvising, learning, hybridizing technologies and knowledge systems, and challenging and negotiating new environmental and social realities. In many cases, these responses seek to manage a variety of shocks and stresses as opposed to specific experienced or projected environmental changes, which is important given the unpredictable nature of environmental change. These findings do not downplay concerns over the speed and magnitude of environmental changes occurring or historical and concurrent socio-economic stressors that erode resilience but rather put them in perspective of Indigenous socio-ecological systems that have often evolved in the context of considerable environmental variability.

Across the examples we review, place has an anchoring role in resilience. Deep links to place create moral relationships of responsibility to protect and care for the environment and provide the foundation for the other resilience factors by shaping belief systems, identity, language, knowledge, and livelihood practices. Many IK systems, for example, are rooted in a deep understanding and connection to specific environments;

Indigenous institutions and collective action produce, reproduce, and sustain the material and socio-cultural values deriving from place; and high levels of agency stem from the confidence derived from place-specific knowledge. In many cultures, relationships with place provide the basis of what it means to be Indigenous by linking the past, present, and future. It is in this context that colonization has been so disruptive and devastating to Indigenous peoples, whereby land dispossession, resettlement, and landscape fragmentation have curtailed and, in some instances, severed links to place. Given the interdependencies between place and resilience, place dislocation has had wide-reaching implications. A commonly described vulnerability pathway evident in studies from diverse regions involved reduced transmission and acquisition of IK among younger generations as a result of land dispossession, which in turn compromised human agency by desensitizing individuals to environmental conditions, undermined collective action by altering relations of trust and reciprocity, and disrupted learning by reducing exposure to the environment. Anthropogenic environmental change acts as an additional (and more recent) stressor to these processes, further compromising links to the environment in many instances. This trajectory is evident even in nations where Indigenous sovereignty and rights are recognized and protected, although to a lesser degree and countered by efforts to reclaim, revive, re-establish, and protect links to place.

These examples illustrate how resilience and vulnerability to environmental change are socially constructed and closely linked to issues of sovereignty, power, social justice, development, and history. Focusing on these root causes needs to be central to efforts to build resilience, including the recognition and protection of Indigenous sovereignty and rights, which—varying by location—can involve political devolution, the settling of land claims, the legal acknowledgment of customary regulations and institutions, the protection of Indigenous lands and resources from outside pressures (including the right of free, prior, and informed consent), and the development of new modes of resource management rooted in IK and Indigenous institutions. Such actions are central to securing what Neef et al.[80] term ''security of place,'' without which more specific interventions targeted to particular environmental changes are likely to be less effective and potentially maladaptive. In such cases, Morrison et al.[125] identify the potential for governance traps, whereby a failure of interventions to address root causes or acknowledge political dynamics results in misdiagnosis of the nature of the problem, constraining and locking actors into responses that are ultimately ineffective or cause harm to Indigenous peoples (see, e.g., Whyte[12]). Over the last decade since the adoption of UNDRIP, progress has been made in many countries in recognizing Indigenous rights. Despite this, a number of nations with large Indigenous populations abstained from UNDRIP, Indigenous peoples globally continue to face significant structural and legal challenges, sovereignty continues to be undermined or unrecognized, many Indigenous languages are in rapid decline, and the inclusion of Indigenous peoples in environmental governance remains limited.[126,127] Environmental change adds further to the urgency of addressing these challenges.

SUPPLEMENTAL INFORMATION

Supplemental Information can be found online at https://doi.org/10.1016/j.oneear.2020.05.014.

ACKNOWLEDGMENTS

The authors thank to three anonymous reviewers who provided detailed and constructive feedback. Carlee Wright produced Figure 1.

AUTHOR CONTRIBUTIONS

J.D.F. conceptualized the research, analyzed data, and wrote the manuscript; N.K. performed the literature search and assisted with writing; E.K.G. helped conceptualize the paper and assisted with writing; S.L.H. helped develop the literature search protocols; and G.M., T.P., and S.L.H. assisted with writing.

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