The sustainability assessment of Indigenous and local knowledge-based climate adaptation responses in agricultural and aquatic food systems

Eranga K. Galappaththi[1] and Anna Schlingmann[2]

[1] Department of Geography, Virginia Polytechnic Institute and State University, Blacksburg, USA
[2] Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona, 08193 Bellaterra, Barcelona, Spain

Highlights

- ILK-based adaptation has high potential for social and environmental sustainability
- Local institutions foster social sustainability through co-management and social networks
- ILK-based conservation and low-input agriculture increase environmental sustainability
- Both risks and benefits are reported for the economic sustainability dimension
- The weakening of ILK systems has the potential to fail sustainable climate adaptation

Abstract

We examine common Indigenous and local knowledge-based adaptive responses to climate change from the sustainability perspective among Indigenous and local communities globally. We draw upon an assessment of 98 peer-reviewed articles to access how local-level responses interact with the broader sustainability dimensions of social, economic, and environmental. We focus on five adaptive responses: 1) community-based adaptation, 2) diversification, 3) local governance and conflict resolution schemes, 4) land, soil, and water management, and 5) traditional weather forecast. Using sustainability framing, we illustrate how these adaptive responses can be both resilient and vulnerable. We argue that long-term successful adaptation to climate change should aim to avoid any increase in, and instead should decrease, vulnerability related to the social (e.g., loss of social bonds and mutual support), economic (e.g., insecure income), and environmental (e.g., soil contamination) dimensions. There is an urgent need to discuss successful adaptation to climate change from a holistic approach that includes long-term social, economic, and environmental sustainability aspects.

Keywords: Indigenous and local knowledge, feasibility, agriculture, fisheries, resilience, sustainability, vulnerability

1_Introduction

Climate change is creating an unprecedented challenge for humanity, undermining progress toward achieving the Sustainable Development Goals (SDGs) and exacerbating ongoing difficulties facing the world's most disadvantaged communities [1,2]. In particular, climate change poses a high risk for Indigenous and local peoples (ILPs) [3,4**]. This reflects the interaction of a combination of factors, including colonization, discrimination, and social exclusion, and directly results in conditions such as a high burden of food insecurity, ill health, and poverty [5–7]. Many of the risks that climate change poses stem from interactions with food systems [8]. Indigenous and local communities typically have "mixed" food systems, deriving significant nutrition from subsistence-based agriculture, hunting, fishing, and foraging, alongside small-scale farming, while also engaging in market activities to sell and obtain food [9,10**]. While these food systems have historically been resilient, the compounding nature of climate risks and, in many cases, government policies has created significant vulnerabilities. At the same time, Indigenous communities are not "agent-less" and helpless; they display a certain resilience to climate change, derived from their profound local and contextualized knowledge and their capacity to adapt to the climate variabilities they have faced over generations [4**].

Indigenous and local knowledge (ILK) is an explicit characteristic of ILPs' adaptive responses associated with their food systems. We understand ILK as an integrated body of knowledge transmitted orally and derived from the accumulation of long-term observations, experiences, and history in the collective memory with communal understanding [11]. Some threads of these knowledge systems are woven into various aspects of the lives of ILPs, whose diverse cultures and traditions helped develop the knowledge required to adapt to a remote environment [12]. ILK is considered a process rather than content, as it co-evolves through an adaptive process and is handed down by cultural transmission from one generation to the next [13]. This knowledge system also faces the serious threat of weakening, as it either has been lost, is not learned by the current generation, or remains undocumented [13]. In this context, this body of knowledge has been fundamental to the environmental, cultural, and livelihood sustainability of ILPs [11].

Previous studies have emphasized the intertwined nature of social-ecological systems and the dependency of economic and social well-being on an entire biosphere [14] as well as the importance of better understanding the nexus between effective adaptation, resilience, and sustainable development [2,15**]. Eriksen et al. [16] identify the integration of local knowledge as one of four key principles for sustainable adaptation, which, per definition, heightens social justice and environmental integrity across spatial and temporal scales while increasing resilience to climate change.

From this perspective, through the sustainability perspective, we identify and examine common ILK-based adaptive responses to climate change among ILPs globally. We draw upon an assessment of 98 peer-reviewed articles published over the last three years (2019-2021) to assess how local-level responses interact with the broader sustainability dimensions (e.g., social, economic, environmental). In structuring our analysis by using sustainability framing, we also illustrate how ILK-based adaptations can be both resilient and vulnerable. We define resilience as the capacity of individuals, communities, and systems to survive, adapt, and self-organize in the face of stress and shocks and even transform when conditions require it [17]. Vulnerability is susceptibility to harm [18]. 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.

2_Methods

2.1_Semi-systematic literature review

This article presents results from a semi-systematic literature review [19], conducted in June 2021, to detect common patterns of ILK-based adaptation to climate change in small-scale agricultural and fishery communities. The underlying work contributed to chapter 5, “Food systems,” in the Sixth Intergovernmental Panel on Climate Change (IPCC) report (IPCC, AR6, WG II, chapter 5, 2022) [20] and focused on scientific literature published between 2019 and June 2021 to capture the most recent research evidence in line with the journal’s publication guidelines.

We applied a two-phase search approach by using the web-based databases Web of Science and Scopus to identify English peer-reviewed publications (Figure 1). In the first phase, we used key search strings based on three sub-topics: 1) Indigenous and local knowledge, 2) climate change, and 3) adaptation (see Table SM1 for specific search terms). This resulted in a list of 402 articles in Web of Science and 316 articles in Scopus. Duplicated articles (n=243) that appeared in both databases were removed. The remaining 475 articles were screened for titles and abstracts. The purpose of this initial screening was to identify major ILK-based adaptation topics for the second phase. The themes were selected based on the number of articles published under each theme, and the depth and breadth of each study. The major adaptation themes were identified for small-scale fisheries (i.e., community-based adaptation, livelihood diversification, and local governance and conflict resolution) and smallholder farmers (i.e., crop diversification, traditional weather forecast, and soil and water management).

In the second phase, we repeated the search with specific key terms corresponding to each of the identified major ILK-based adaptation strategies to find the most study-relevant articles (see Table SM1 for specific search terms). From the total list of articles derived from phases 1 and 2, we selected approximately 15 articles per theme (or adaptation strategy) that best met the following criteria based on the authors’ assessment of: 1) topic relevance, 2) quality criteria, 3) level of details of results, and 4) diversity in the geographic distribution of case studies.

We also added nine articles that subject experts recommended but that did not appear in our search list. For the included articles and each adaptation theme, we conducted a qualitative analysis by assessing common patterns of benefits, costs, and trade-offs regarding the three sustainability dimensions (social, economic, and environmental), in line with social, economic, and environmental feasibility indicators developed by Singh et al. [29]. The supplementary materials contain a list of documents reviewed and a data sheet.

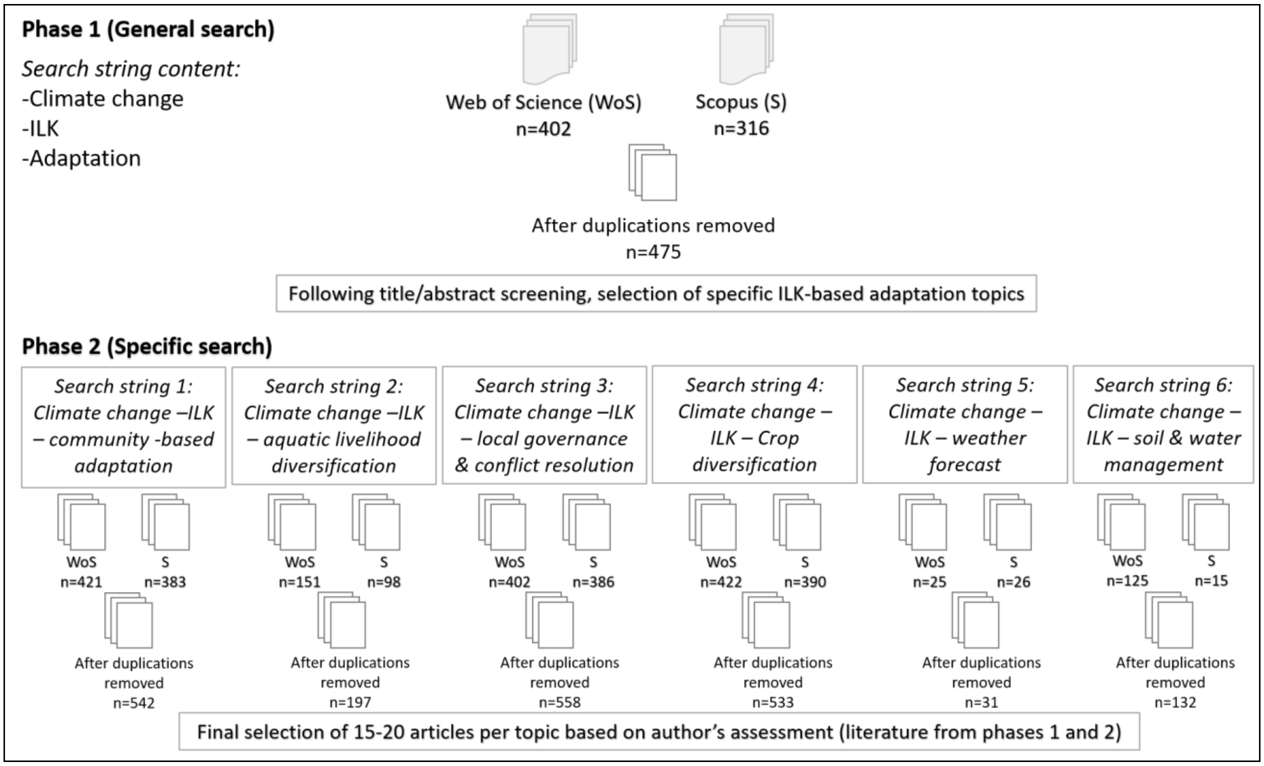

Figure 1: The two-phase search approach.

2.2_Adaptive responses and sustainability

We focus specifically on five adaptive responses in the context of Indigenous and local knowledge: 1) community-based adaptation, 2) diversification, 3) local governance and conflict resolution schemes, 4) land, soil, and water management, and 5) traditional weather forecast. Community-based adaptation refers to adaptive responses emerging from the local level (individual, household, community) to address climate-related risk [21]. Diversification can take various forms including diversification of livelihood activities and assets such as crop species and varieties and fisheries to minimize climate vulnerability by increasing the range of options available [22]. Local governance and conflict resolution schemes refer to community-level resource governance partnerships occurring at multiple levels (community to government) in managing food systems to deal with climate risk. This can include community-based management and co-management approaches for natural resources [23]. Soil management includes (no-)tillage, plowing, mulching, ridge and furrow, and terrace cultivation with the general goal of increasing soil quality and water retention capacity [24*]. Water management refers to different types of irrigation and water conservation practices. Traditional weather forecasts use the ILK of biophysical indicators such as animals, plants, weather phenomena, and celestial bodies to predict upcoming weather and thereby plan daily and seasonal livelihood activities (e.g., [25]).

Adaptive responses are key to the sustainability of Indigenous and local food systems. We understand sustainability in a climate change adaptation context as the combined result of the long-term dynamics of the resilience and vulnerability of human-environmental systems [16,26]. Social, economic, and environmental dimensions are various archetypical pathways of sustainability shaped by various adaptive responses. Specifically, the social dimension of sustainability refers to social equality and justice, including food, health, education, and gender aspects; the economic dimension to economic equality, including decent work, economic growth, and responsible production; and the environmental dimension to the integrity of terrestrial and aquatic systems, including the climate [14]. Adaptive responses can generate mixed positive and negative impacts along the social, economic, and environmental dimensions of sustainability. When adaptive responses show evidence of generating more resilience than vulnerability (along the three dimensions of sustainability), they are identified as having a positive impact. On the other hand, high economic, social, or environmental costs constitute maladaptation [27,28].

Table 1: Three dimensions and indicators of sustainability to assess adaptation in Indigenous and local contexts (adopted from [29])

Sustainability dimensions	Indicators	Questions asked with adaptation indicators	References
Social	Social benefits	Does the option offer health and education benefits? Does the option minimize negative trade-offs with other development policy goals and identify positive synergies with other policy goals?	[30]
	Sociocultural acceptability	Is there public resistance to the option? Does the option typically find acceptance within existing sociocultural norms and utilize diverse knowledge systems including Indigenous and local knowledge?	[31–33]
	Social and regional inclusiveness	Does the option include different social groups and remote regions? Does the adaptation option adversely affect vulnerable groups or other areas?	[34–36]
Economic	Microeconomic and macroeconomic viability, including employment and productivity enhancement potential	What are the economic costs and trade-offs of the option? (high costs correspond to low feasibility) Would the option lead to higher economic productivity? Does the option employ many people or does the system's productivity increase under the option?	[37,38]

Environmental	Adaptive capacity/ resilience-building potential	Does the option enhance the ability of ecosystems or relevant decision-makers to adjust to potential damage to the environment, take advantage of opportunities, or respond to consequences, or does the option contribute to building resilience (the environment's ability to cope with stressors and reorganize to maintain structures and functions and retain the capacity to transform)?	[39]
	Ecological capacity	Does the option enhance supporting, regulating, or provisioning ecosystem services in any way?	[39]

3. Results

3.1_Social sustainability

We found records of diverse ILK-based adaptive responses leading to social sustainability. Community-based adaptation has a widely documented ability to positively impact social sustainability. For example, based on two case studies from the Solomon Islands, Basel et al. [40] found that the community-based adaptation approach could address key climate change vulnerabilities (e.g., climate variability, extreme events), additional drivers of social vulnerability (e.g., limited equity and inclusion, education), and adaptive capacity (e.g., leadership, youth capacity building). However, from the same islands, Van der Ploeg et al. [41*] found that several other interconnected social and political problems such as youth unemployment, poor healthcare and education, gender-based violence, land tenure disputes, corruption, alcoholism, urbanization, and expectations of modernity could lead to food insecurity and health problems.

Local governance and co-management arrangements are recorded among the Indigenous fisheries systems of northern Canada and Sri Lanka as a way of building the resilience of social-ecological systems and fostering adaptation to climate change. For example, both the DFO (Department of Fisheries and Oceans) and the HTA (Hunters and Trappers Association), along with the NWMB (Nunavut Wildlife Management Board) and other designated Inuit organizations, are co-managers of the fisheries in Nunavut, Canada as outlined in the Nunavut Agreement Article 5 [42]. Some community fisheries such as Cambridge Bay and Pangnirtung have been using co-management for the last three decades [43]. These co-managers use the best available ILK and science for decision-making related to annual fish quotas and fishing places. For instance, transformative changes such as food system changes (e.g., from land-based to ocean-based) recorded in Pangnirtung were fostered by the local perception of environmental change, sustained monitoring programs, shared narratives, and the interaction between knowledge systems, facilitated by a bridging organization within a broader process of governance transformation [43]. Similar co-management characteristics have been documented in Sri Lankan Coastal-Vedda culture-based fisheries [44]. Co-management is not an easy adaptive response but is the best available collaborative management solution for Indigenous and local resource systems [45].

Across the globe, Indigenous and local crops and varieties are an integral part of local cultures and therefore play an important role in customary traditions and local diets; they are often associated with a better taste and, consequently, are culturally highly accepted [46*–51]. A mixed cropping system and the complementation of cultivated crops with medicinal plants has additional social benefits for health such as the potential to diversify the food and nutritional intake of ILPs and the supply of low-cost medical treatments [46*,47**,52–55]. Social structures such as traditional seed networks and communal labor are important factors in preserving local seeds, crop diversity, and crop quality [50,51], pooling labor in times of intensive farming activities, and supporting each other in times of climate emergency, as practiced by the Lun Bawang, Sa'ban, and Penan peoples on the island of Borneo [56].

The strong link between ILK-based adaptive strategies and customary institutions is also evident in the context of traditional weather forecasts. Information and knowledge sharing through customary institutions are crucial for the collection and interpretation of weather indicators and the evaluation, correction, and dissemination of the final forecasts [57–59]. Similar to Indigenous crops, traditional weather forecasts have been transmitted through generations and therefore display high cultural acceptance and trust (e.g., [59–61]).

Indigenous institutions are also crucial for controlling, regulating, and guaranteeing the balanced, equal, and sustainable use of water, an often limited good [62]. Additionally, social capital in the form of collective actions is visible in work-intensive soil and water management practices such as community-based pasture management in the Andes [63] and chena cultivation and large-scale water tank systems in Sri Lanka [64].

However, evidence indicates that local culture and customary institutions are weakening, which threatens social cohesion and resilience to climate change. For example, studies report declines in the cultivation of Indigenous and local crop varieties [46*,48], the application of Indigenous cropping systems, seed exchange between farmers [48], and the application of customary water control systems and governance [64].

3.2_Economic sustainability

The economic dimension of sustainability addresses uncertainties associated with Indigenous and local food systems. This includes various diversification responses as well as the application of traditional weather forecasts. Crop diversification is documented for microeconomic viability. A shift from subsistence to market integration is highly correlated with a shift toward cash crops (e.g., fruits, vegetables, wheat, and coffee) and improved and hybrid varieties [46*,47**,50,65]. This trend is strongly driven by certain economic benefits such as higher yields, shorter growing cycles, lower labor demand, and higher market values, which potentially increase income and food security [46*–48,51,52,66]; the exception is [67]. The economic trade-offs of improved and hybrid varieties are often neglected. For example, direct costs arise because hybrid varieties cannot be self-saved but must be purchased for each season [47**,48,50,55]. Indirect costs arise because improved varieties and cash crops often require more chemical fertilizer and pesticides as well as a cost-intensive irrigation infrastructure [47**,48,50]. These economic downsides imply two consequences: 1) Indigenous crops have a higher energy use efficiency ratio as shown in a case study involving Nepalese and Bangladeshi farmers [46*] and 2) Indigenous crops imply lower economic risks in a high-climate-risk year, due mainly to their lower investment costs [47**,68]. Furthermore, Indigenous cropping practices like intercropping or relay cropping have the potential to increase yield per area compared to mono-cropping systems [54,66,68]. Economic value also arises through the incorporation of Indigenous medicinal plants and the generally better straw quality of Indigenous crops [47**,50,52,55].

Livelihood diversification is recorded in different forms as an adaptive response allowing rural populations to be involved in a range of activities that reduce their economic vulnerability. For example, Inuit of the Canadian Arctic are involved in co-existing fisheries (commercial and subsistence; Arctic Char—*Salvelinus alpinus* and Turbot—*Reinhardtius hippoglossoides*) that create more economic opportunities [42]. In the Global South, Sri Lankan Coastal-Vedda are involved in multiple casual livelihood activities allowing them to shift between different livelihood options (e.g., culture-based fisheries, rice farming, home gardening) [44]. However, in the context of economic diversification (as a main adaptive strategy), a peri-urban lake system in Zimbabwe records that males dominate the leadership of fishing cooperatives and that women (who are often low-paid or unpaid, with an unofficial status) are not recognized for their roles (e.g., net making, fish gutting, cleaning, and gleaning) [69].

Adequate weather forecasts are crucial for stabilizing yields, avoiding yield losses, and maximizing crop revenues. Compared to state-led weather forecasts, traditional weather forecasts display certain economic and technological advantages, i.e., they are low-cost and low-tech, though additional costs and required technological infrastructure and understanding of state institutional weather forecasts are significant access impediments, especially for remote communities [25,53,55,59,61,70,71]. For example, based on evidence from studies in Zimbabwe, Mexico, Uganda, and Botswana, the scarcity of weather stations in remote regions, which results in a low spatial resolution of institutional weather forecasts, often presented at the regional level or even state level, is criticized as being too broad in its application and use at the local level and misaligned with farmers' needs [58,60,61,70]. Additionally, temporal delays in state forecast dissemination place a burden on its local applicability [59,70].

3.3_Environmental sustainability and climate resilience

Many Indigenous crops such as millet, buckwheat, quinoa and qañawa, yam and cocoyam, and cassava, and their wild relatives, have adapted to harsh environmental conditions, including extreme cold droughts and floods [46*,48,49,55,68,72], and are less susceptible to pests and diseases [47**,48,55,68]. Therefore, the general demand for external inputs, such as pesticides, fertilizer, and irrigation, and, consequently, the environmental impacts, especially on soil and water, is generally lower for Indigenous crops [47**,53]. Instead, traditional crop cultivation depends on natural fertilizers and pesticides [48,55,65] or dung from (free-range) livestock [47**]. An example from Sri Lanka shows that chena cultivation systems use less artificial fertilizer and pesticides, depending instead on natural soil fertility [64]. We therefore argue that many Indigenous and local crops and varieties combine general climate resilience and environmental sustainability. However, the short maturation cycles of crops such as maize, groundnut, and cowpea and the improved short-cycle varieties increase their drought resistance by advancing their flowering and harvest dates compared to those of Indigenous crop varieties such as guinea corn and late millet; this results in a decline in the cultivation of Indigenous crops [53,66]. On the other hand, traditional mixed cropping systems decrease the risk of complete crop failure and contribute to agrobiodiversity and increased soil quality [24*,49,51,53,65]. Similarly, soil conservation based on Indigenous and local knowledge is generally environmentally sustainable because of its low demand for energy and chemical products with the aim of increasing soil fertility and water retention capacity in an environmentally sustainable manner.

Local governance involves community-based efforts to face common challenges using collective action and local institutions, sometimes with the support of the government. Records from Sri Lanka show how small-scale shrimp farmers collectively use their local knowledge of shrimp disease spreading patterns across the interconnected lagoon waterbody to implement a zonal crop calendar system by managing water withdrawal and discharge [42]. Also in the Pacific Islands, [73**] recorded how local governance of iTaukei (Indigenous Fijian) communities sustainably managed mangrove ecosystems over time and how this knowledge and these experiences can produce more sustainable and effective ecosystem-based adaptation options in the future. iTaukei indicates that mangrove plantations can prevent soil from washing away and can act as natural barriers to protect the coastline from sea-level rise, storm surges, and coral damage. However, there is not enough scientific data to facilitate sustainable environment management practices, for example, in the context of Arctic fisheries experiencing rapid environmental and climate change [74].

Traditional weather forecast methods are used to determine seasonal activities such as the timing of crop planting and harvesting and the seasonal selection of crop species and varieties (e.g., [58,68,71,75]) and livestock activities [59] to prepare for expected climate emergencies such as drought and flooding [25,60,70,71,75] as well as for adapting to long-term changes in local climates [60,71]. However, nowadays, traditional weather forecast practices are threatened not only by cultural loss but also by the unprecedented speed of anthropogenic climate change itself, as shown in case studies from Malaysian Borneo [56] and Ethiopia [25]. Several communities lament a decrease in the reliability and accuracy of traditional weather forecasts, as weather is more variable and rainfall more erratic nowadays and the relationships between biophysical indicators and weather phenomena are weakening [56,61]. Nonetheless, the question of whether relying on institutional or traditional weather forecast methods is more accurate and implies fewer risks of error is not a trivial one, as [76] exemplified in a case study in Nigeria.

Table 2: Examples of Indigenous and local knowledge-based adaptation responses and their impacts on sustainability

Adaptive responses	Examples	(+/–) Impacts on sustainability	Sustainability dimensions	References
Community-based adaptation	Participatory adaptation planning (Langalanga people from the Solomon Islands)	(+) Support community cohesion, local resource management (forest, water, and fisheries), and disaster risk reduction (-) Increased settlement along the coast leads to conflicts over access to fishing grounds	Social, Environmental	[40,41*]
	Inclusion of women in fisheries (Alaskan native people, United States)	(+) Inclusion of women's knowledge in fisheries decision-making (Alaskan native people, United States) (-) Limited research considering the knowledge and perspectives of fisherwomen in Alaska (Alaskan native people, United States)	Social	[77**]
Diversification	Livelihood diversification (Indigenous peoples in the Asia Pacific region)	(+) Diverse skills give them opportunities to maximize the flexible use of all available capital to sustain their livelihood and reduce climate risks and vulnerability (-) Limited specialization in one livelihood activity (expert knowledge and learning)	Economic, Social	[3,44]

	Crop diversification (Bangladesh; Milpa farmers in Mexico; various ethnic groups in northern Vietnam; Yi people in China)	(+) Contribution to agrobiodiversity, improved soil quality, reduced pest infestation, health and nutritional intake diversity (-) Although mixed cropping increases yield, indigenous crops generally display lower yields and lower market prices, resulting in generally lower income generation potential compared to improved varieties	Environmental, Economic, Social	[51,54,55,67]
Local governance and conflict resolutions schemes	Co-management (small-scale fishers in Timor-Leste and Bangladesh)	(+) Empowered communities are more likely to meet both socio-economic and biological goals being involved in decision-making (-) Inequities reinforced by the customary power hierarchies reduce incomes and access rights of poor fishers	Social, Economic, Environmental	[78,79]
	Community-based management (Laos PDR, Resex Pirajubaé fishers of Brazil)	(+) Foster capacity building (-) Degradation of coastal-marine ecosystems and a severe impact on traditional fishery did not prevent due to urban growth over the reserve	Social, Environmental	[80,81]
Land, soil, and water management	Soil management (Thai farmers in Vietnam; smallholder farmers in Northern Ghana; Khasi and Jaintia people in Northern India)	(+) Improves soil quality, including soil fertility and water retention potential (-) Labor work-intensive, which is addressed through collective actions and a culture of reciprocity	Environmental, Economic, Social	[82,83]

	Water management (Sri Lanka; Peruvian Andean Indigenous pastoralists; Northern Pakistan)	(+) a good water management systems guarantees sustainable and fair water use among community members (-) Excessive water usage in the dry season might exhaust natural water sources	Social, Economic, Environmental	[62–64]
Traditional weather observation and forecast	Traditional weather forecast (Alfa pastoralists in Ethiopia; Mayan milpa farmers in Mexico)	(+) High cultural acceptance, Information sharing to inform all community members (-) The higher unpredictability especially of rainfall, makes traditional weather forecast less reliable and decision-making more difficult	Social, Economic	[57,61]

4_Discussion

We have investigated the most recently recorded evidence covering diverse regions and peoples to understand how these ILK-based adaptive responses can generate mixed positive and negative impacts along the social, economic, and environmental dimensions of sustainability. Across the examples we review, Indigenous and local knowledge provide the context for adaptive responses to foster the resilience and sustainability of agricultural and aquatic food systems. However, we have also seen that performance in the different domains of sustainability varies. While the reviewed strategies show specifically high potential to increase social and environmental sustainability, there are reported trade-offs in the economic sustainability domain. Therefore, strengthening ILK-based adaptation can enrich climate change resilience while contributing to the social and environmental SDG, for which low achievements have been reported thus far [84,85].

We find numerous records of adaptation in Indigenous food systems across diverse regions that are resilient to climate change and sustainable in many aspects. For example, the zaï cultivation system improves soil qualities, increases yields, and reduces climate impacts [86]. However, we also find examples of sustainable trade-offs, especially regarding the economic domain, and argue that populations can be both resilient and vulnerable. For example, the high landrace diversity of buckwheat of the Yi people in China makes them resilient to climate variability but vulnerable to market conditions [51]. Furthermore, some of the adaptive responses that we document are being undermined or challenged to varying degrees, differing by (and within) populations; an example is the lack of capacity among Indigenous peoples on the Cook Islands to practically integrate and apply ILK in climate change adaptation planning [87].

We argue that long-term successful adaptation to climate change should aim to avoid any increase in, and instead should reduce, social (e.g., loss of social bonds and mutual support), economic (e.g., food insecurity due to poverty), and environmental (e.g., soil contamination) vulnerability [27,28,88]. However, due to the complexity of climate change and adaptation in a sociopolitical context, trade-offs and maladaptive outcomes are omnipresent, even when the best intentions exist [89,90]. There is consequently an urgent need to discuss successful adaptation to climate change through a holistic approach that includes, inter alia, long-term social, economic, and environmental sustainability aspects and to consider ILK [88]. This is especially important because 1) Indigenous and local food systems are undergoing rapid change due to environmental and climate change [4**] and 2) these changes are not experienced in isolation but in a context of various socio-economic, cultural, and political stressors [9]. In other words, these various place-based conditions shape the way people respond to climate change impacts and determine the long-term and system-wide efficiency and sustainability of adaptation and, thus, the resilience and vulnerability of human-environmental systems [4**].

Many ILK systems are rooted in a deep understanding and represent a process of social-ecological memory accumulated over several generations [91]. Also, these ILK systems are connected to specific environments (e.g., food systems) and social processes (e.g., livelihood) shaped by shocks and stressors over the long term [4**]. Additionally, as shown in our and other studies, ILPs are characterized by the high importance of social capital through the practice of collective action and collaboration (e.g., food sharing), local institutions (e.g., farmers associations), human agency (e.g., assets), and learning (e.g., learning-by-doing) [4**,10**,42]. These characteristics can shape adaptive responses in the ILK setting and provide evidence for building the resilience and sustainability of food systems. Furthermore, culture, beliefs, and a high connection with and respect for nature foster sustainable resource use and impede any other harm to the natural environment, implemented and controlled through customary institutions and codes of ethics [92].

In our study, we find that some ILK systems are experiencing a weakening of knowledge systems and that this has the potential to result in the failure of sustainable adaptive capacity or increase exposure and sensitivity to climate impacts and other impacts [10**,31]. The weakening of ILK could stem from distractions in a process of social-ecological memory accumulation, for example, the loss of language and cultural and livelihood practices (e.g., toward off-farm activities), relocation, and increasing external influences, such as extension services and schooling (Sri Lankan Coastal-Vedda believe that aspects of their ILK system are weakening, due partly to three decades of ethnic conflict and social modernization) [10**,44]. In the Canadian Arctic, some aspects of Inuit knowledge systems are weakening, as many elders possess knowledge but do not practice it themselves. For example, some young Inuit have not had to use survival skills on the ice, nor have they handled dog teams, read the sky, or sewn seal skin [10**,42]. Thus, while ILK systems could result in resilience, their weakening could lead to vulnerability. Such weakening could lead to, for example, more environmental degradation (e.g., through the increased application of chemical fertilizers and pesticides as promoted by many extension services, a loss of local resources, and unconstrained overexploitation of water resources for the irrigation of cash crops) [47**] and a decrease in social bounds and the ethics of reciprocity. Therefore, several studies support the application of hybrid knowledge that combines ILK and scientific knowledge [93]. This can be a promising tool based on the premise of a decolonized and respectful exchange with a common understanding that both knowledge systems are equally valid, without any temptation to outperform each other, and guaranteeing the preservation of local culture and beliefs. Some examples of the successful application of such "hybrid knowledge" are reported for natural resource management including water, fisheries, and mountainous ecosystems (e.g., [51,53,93]).

Given the multiple policy challenges demanding joint solutions that seek to bring together sustainable development, climate change action, and disaster risk reduction, this assessment is conceptualized as an initial step toward building a broad understanding of sustainable climate adaptation responses in the context of ILK and their food systems. The five ILK-based adaptive responses are: community-based adaptation; diversification; local governance and conflict resolution schemes; land, soil, and water management; and traditional weather forecast. These adaptive responses have significant potential for social and environmental sustainability but ILK remains challenged and disadvantaged under economic aspects. ILK-based adaptive strategies can show trade-offs in fostering resilience regarding one dimension of sustainability while increasing vulnerability regarding another. The weakening of ILK systems can potentially fail and be maladaptive in terms of sustainable climate adaptation. The policy focusing on successful adaptation should aim at sustainability's social, economic, and environmental dimensions. Our assessment serves as a learning platform to anticipate urgent adaptation policies and envisions sustainable solutions to a wide range of fast-warming, small-scale agricultural and aquatic food systems worldwide.

Acknowledgments:
The research leading to this paper has received funding from multiple sources. EKG received funds from the International Development Research Centre-IDRC (108279-008) and the Social Science and Humanities Research Council-SSHRC (752-2016-0148). AS received funds from the European Research Council under an ERC Consolidator Grant (FP7-771056-LICCI) --this work contributes to the "María de Maeztu" Programme for Units of Excellence of the Spanish Ministry of Science and Innovation (CEX2019-000940-M).

References

1. Yap ML-M, Watene K: **The sustainable development goals (SDGs) and indigenous peoples: another missed opportunity?** *Journal of Human Development and Capabilities* 2019, **20**:451–467.

2. Fuso Nerini F, Sovacool B, Hughes N, Cozzi L, Cosgrave E, Howells M, Tavoni M, Tomei J, Zerriffi H, Milligan B: **Connecting climate action with other Sustainable Development Goals**. *Nature Sustainability* 2019, **2**:674–680.

3. Shaffril HAM, Ahmad N, Samsuddin SF, Samah AA, Hamdan ME: **Systematic literature review on adaptation towards climate change impacts among indigenous people in the Asia Pacific regions**. *Journal of cleaner production* 2020, **258**:120595.

4. **Ford JD, King N, Galappaththi EK, Pearce T, McDowell G, Harper S: Resilience of Indigenous peoples to environmental change. *One Earth* 2020, 2:532–543.**

**Based on a systematic review of 227 articles, this study examines 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. The study recognizes the importance of a place that provides a foundation for belief systems, identity, knowledge, and livelihood practices that underlie mechanisms through which environmental change is experienced. It further discusses vulnerabilities associated with colonization, globalization and development patterns.

5. Huang S-M: **Understanding disaster (in) justice: Spatializing the production of vulnerabilities of indigenous people in Taiwan**. *Environment and Planning E: Nature and Space* 2018, **1**:382–403.

6. Leite MS, Ferreira AA, Bresan D, Araujo JR, Tavares I do N, Santos RV: **Indigenous protagonism in the context of food insecurity in times of Covid-19**. *Revista de Nutrição* 2020, **33**:e200171.

7. Comberti C, Thornton TF, Korodimou M, Shea M, Riamit KO: **Adaptation and resilience at the margins: Addressing indigenous peoples' marginalization at international climate negotiations**. *Environment: Science and Policy for Sustainable Development* 2019, **61**:14–30.

8. Lemke S, Delormier T: **Indigenous Peoples' food systems, nutrition, and gender: Conceptual and methodological considerations**. *Maternal & Child Nutrition* 2017, **13**:e12499.

9. FAO: **The White/Wiphala Paper on Indigenous Peoples' food systems. Rome. https://doi.org/10.4060/cb4932en**. 2021,

10. **Galappaththi EK, Ford DJ, Bennett EM, Berkes F: Adapting to climate change in small-scale fisheries: Insights from Indigenous communities in the global north and south. *Environmental Science and Policy* 2021, 116:160–170.**

**Based on a comparative analysis of two case studies from the Canadian Arctic (Inuit) and Sri Lanka (Coastal-Vedda), this study investigates how different Indigenous fisheries systems experience and respond to climate change impacts. Two key adaptive strategies emerged in common across the two communities – diversification and adaptive co-management. Eight sources of resilience that underpin adaptive capacity: i) use of diverse kinds of knowledge; ii) practice of different ways of learning; iii) use of community-based institutions; iv) efforts to improve human agency; v) unique worldviews; vi) specific cultural attributes that keep up with adaptation; vii) effective social networks; and viii) a high level of flexibility. Definitive characteristics that need to promote successful community adaptation: continuous learning through knowledge co-production; capacity-building to improve human agency; a place-specific nature (rootedness); collective action and partnerships through community-based institutions; and flexibility.

11. Berkes F: *Sacred ecology*. Routledge; 2018.

12. Maldonado J: **Engagement with indigenous peoples and honoring traditional knowledge systems**. *Climatic Change* 2016, **135**:111–126.

13. Kitolelei S, Thaman R, Veitayaki J, Breckwoldt A, Piovano S: **Na Vuku Makawa ni Qoli: Indigenous Fishing Knowledge (IFK) in Fiji and the Pacific**. *Frontiers in Marine Science* 2021, **8**.

14. Folke C, Biggs R, Norström A, Reyers B, Rockström J: **Social-ecological resilience and biosphere-based sustainability science**. *Ecology and Society* 2016, **21**.

15. **Singh C, Iyer S, New MG, Few R, Kuchimanchi B, Segnon AC, Morchain D: Interrogating 'effectiveness' in climate change adaptation: 11 guiding principles for adaptation research and practice. *Climate and Development* 2022, 14:650–664.**

**Based on a literature review of 243 publications, this study response to the conceptual and methodological challenges in framing effective adaptation. It synthesizes 11 principals of effective adaptation, among others avoided maladaptation, reduced vulnerability and costs, and increased resilience, sustainability, ecosystem conservation, wellbeing, economic benefits, social justice and equity. It further applies those principles to empirical data from cases in Africa and Asia.

16. Eriksen S, Aldunce P, Bahinipati CS, Martins RD, Molefe JI, Nhemachena C, O'brien K, Olorunfemi F, Park J, Sygna L: **When not every response to climate change is a good one: Identifying principles for sustainable adaptation**. *Climate and development* 2011, **3**:7–20.

17. Brown K: *Resilience, development and global change*. Routledge; 2016.

18. Arora-Jonsson S: **Virtue and vulnerability: Discourses on women, gender and climate change**. *Global Environmental Change* 2011, **21**:744–751.

19. Snyder H: **Literature review as a research methodology: An overview and guidelines**. *Journal of Business Research* 2019, **104**:333–339.

20. Bezner Kerr R, Hasegawa T, Lasco R, Bhatt I, Deryng D, Farrell A, Gurney-Smith H, Ju H, Lluch-Cota S, Meza F, et al.: **Food, Fibre, and Other Ecosystem Products**. In *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)].* . Cambridge University Press, Cambridge, UK and New York, NY, USA; 2022:713–906.

21. Ensor JE, Park SE, Attwood SJ, Kaminski AM, Johnson JE: **Can community-based adaptation increase resilience?** *Climate and Development* 2018, **10**:134–151.

22. Asfaw S, Pallante G, Palma A: **Diversification strategies and adaptation deficit: Evidence from rural communities in Niger**. *World Development* 2018, **101**:219–234.

23. Plummer R, Baird J: **Adaptive co-management for climate change adaptation: Considerations for the Barents Region**. *Sustainability* 2013, **5**:629–642.

24. **Rivera-ferre M, Di Masso M, Vara I, Cuellar M, López-i-Gelats F, Bhatta G, Gallar D: Traditional agricultural knowledge in land management: the potential contributions of ethnographic research to climate change adaptation in India, Bangladesh, Nepal, and Pakistan. *Climate and Development* 2021, 13:644–661.**

*****This literature review with a regional focus on India, Bangladesh, Nepal and Pakistan highlights the importance of traditional agricultural knowledge (TAK) for minimizing climate change impacts. It argues that TAK-based land and soil management such as organic manuring and composting, diversified cropping patterns such as intercropping, rotational and relay cropping, land preparation, mulching and fallowing, and terracing, contributes to soil and water conservation and thereby displays high potentials for climate change adaptation, yet however often untapped in ethnographic research.

25. Iticha B, Husen A: **Adaptation to climate change using indigenous weather forecasting systems in Borana pastoralists of southern Ethiopia**. *Climate and Development* 2019, **11**:564–573.

26. Bhatasara S, Nyamwanza A: **Sustainability: a missing dimension in climate change adaptation discourse in Africa?** *Journal of Integrative Environmental Sciences* 2018, **15**:83–97.

27. Barnett J, O'Neill S: **Maladaptation**. *Global Environmental Change* 2010, **20**:211–213.

28. Juhola S, Glaas E, Linnér B-O, Neset T-S: **Redefining maladaptation**. *Environmental Science & Policy* 2016, **55**:135–140.

29. Singh C, Ford J, Ley D, Bazaz A, Revi A: **Assessing the feasibility of adaptation options: methodological advancements and directions for climate adaptation research and practice**. *Climatic Change* 2020, **162**:255–277.

30. Jordan AJ, Huitema D, Hildén M, Van Asselt H, Rayner TJ, Schoenefeld JJ, Tosun J, Forster J, Boasson EL: **Emergence of polycentric climate governance and its future prospects**. *Nature Climate Change* 2015, **5**:977–982.

31. Pearce T, Ford J, Willox AC, Smit B: **Inuit traditional ecological knowledge (TEK), subsistence hunting and adaptation to climate change in the Canadian Arctic**. *Arctic* 2015, **68**:233.

32. Singh C, Osbahr H, Dorward P: **The implications of rural perceptions of water scarcity on differential adaptation behaviour in Rajasthan, India**. *Regional Environmental Change* 2018, **18**:2417–2432.

33. Tschakert P, Barnett J, Ellis N, Lawrence C, Tuana N, New M, Elrick-Barr C, Pandit R, Pannell D: **Climate change and loss, as if people mattered: values, places, and experiences**. *Wiley Interdisciplinary Reviews: Climate Change* 2017, **8**:e476.

34. Sovacool BK, Linnér B-O, Goodsite ME: **The political economy of climate adaptation**. *Nature Climate Change* 2015, **5**:616–618.

35. Ford JD, Labbé J, Flynn M, Araos M, Team IR: **Readiness for climate change adaptation in the Arctic: a case study from Nunavut, Canada**. *Climatic change* 2017, **145**:85–100.

36. Shi L, Chu E, Anguelovski I, Aylett A, Debats J, Goh K, Schenk T, Seto KC, Dodman D, Roberts D: **Roadmap towards justice in urban climate adaptation research**. *Nature Climate Change* 2016, **6**:131–137.

37. Chakrabarty S, Boksh F, Chakraborty A: **Economic viability of biogas and green self-employment opportunities**. *Renew Sustain Energy Rev* 2013, **28**:757–766.

38. Dalton G, Allan G, Beaumont N, Georgakaki A, Hacking N, et al.: **Economic and socio-economic assessment methods for ocean renewable energy: Public and private perspectives**. *Renew Sustain Energy Rev* 2015, **45**:850–878.

39. Berbés-Blázquez M, Mitchell C, Burch S, Wandel J: **Understanding climate change and resilience: assessing strengths and opportunities for adaptation in the Global South**. *Climatic Change* 2017, **141**:227–241.

40. Basel B, Goby G, Johnson J: **Community-based adaptation to climate change in villages of Western Province, Solomon Islands**. *Mar Pollut Bull* 2020, **156**:111–266.

41. **van der Ploeg J, Sukulu M, Govan H, Minter T, Eriksson H: Sinking Islands, Drowned Logic; Climate Change and Community-Based Adaptation Discourses in Solomon Islands. *Sustainability* 2020, 12:7225.**

*****Using a qualitative content analysis, this paper tries to contextualize the claims made in 73 newspaper articles and reconstruct local socio-ecological events through an iterative process of inference and induction. This study investigates the sinking islands narrative, and argues that a narrow focus on the projected impacts of climate change distracts attention and resources from more pressing environmental and development problems that are threatening rural livelihoods.

42. Galappaththi EK, Ford DJ, Bennett EM, Berkes F: **Climate change and community fisheries in the Arctic: A case study from Pangnirtung, Canada**. *Journal of Environmental Management* 2019, **250**:11.

43. Galappaththi EK, Falardeau M, Harris LN, Rocha JC, Moore J-S, Berkes F: **Resilience-based steps for adaptive co-management of Arctic small-scale fisheries**. *Environmental Research Letters* 2022, **17**:083004.

44. Galappaththi EK, Ford JD, Bennett EM: **Climate change and adaptation to social-ecological change: the case of indigenous people and culture-based fisheries in Sri Lanka**. *Climatic Change* 2020, **162**:279–300.

45. Berkes F: *Toward A New Social Contract: Community-based Resource Management and Small-scale Fisheries*. TBTI Global; 2021.

46. **Adhikari L, Tuladhar S, Hussain A, Aryal K: Are Traditional Food Crops Really 'Future Smart Foods?' A Sustainability Perspective. *Sustainability* 2019, 11:5236.**

*****This study draws on a case study in Nepal to assess and discuss the social, environmental and economic sustainability of traditional food crops (TFCs). It concludes that TFCs have huge potentials for being 'future smart foods' due to their high nutritional values, their key contribution to agrobiodiversity and resilience of farming systems and their efficient energy use, among other factors. However much stronger efforts towards the promotion of TFCs are required to revitalize them in local farming systems.

47. **Dhakal B, Kattel R: Effects of global changes on ecosystems services of multiple natural resources in mountain agricultural landscapes. *Sci Total Environ* 2019, 676:665–682.**

******This study provides detailed information on the positive and negative effects of external factors on ecosystem services in a case study in Nepalese mountain farming communities. Reported positive effects refer to amenity amelioration, hazard moderation, habitat conservation, water supply and recreational ecosystem services. Seriously degraded or extinct indigenous species and genetic diversity, and a decline in soil quality, water conservation, local knowledge systems and spiritual ecosystem services are among the negative impacts.

48. Ndalilo L, Wekesa C, Mbuvi M: **Indigenous and Local Knowledge Practices and Innovations for Enhancing Food Security Under Climate Change: Examples from Mijikenda Communities in Coastal Kenya**. In *Sustainability Challenges in Sub-Saharan Africa II: Insights from Eastern and Southern Africa.* Edited by Gasparatos A, Naidoo M, Ahmed A, Karanja A, Fukushi K, Saito O. Springer; 2020:63–82.

49. Dutta S, Maiti S, Garai S, Abrar F, Jha S, Bhakat M, et al.: **Analyzing adaptation strategies to climate change followed by the farming community of the Indian Sunderbans using Analytical Hierarchy Process**. *J Coast Conserv* 2020, **24**:61.

50. Ravera F, Reyes-García V, Pascual U, Drucker A, Tarrasón D, Bellon M: **Gendered agrobiodiversity management and adaptation to climate change: differentiated strategies in two marginal rural areas of India**. *Agric Hum Values* 2019, **36**:455–474.

51. Song Y, Dong Y, Wang Y, Feng J, Long C: **Tartary buckwheat (Fagopyrum tataricum Gaertn.) landraces cultivated by Yi people in Liangshan, China.** *Resour Crop Evol* 2020, **67**:745–761.

52. Singh R, Kumar A, Singh A, Singhal P: **Evidence that cultural food practices of Adi women in Arunachal Pradesh, India, improve social-ecological resilience: insights for Sustainable Development Goals.** *Ecol Process* 2020, **9**:29.

53. Chaudhary B, Acciaioli G, Erskine W, Chaudhary P: **Responses of the Tharu to climate change-related hazards in the water sector: Indigenous perceptions, vulnerability and adaptations in the western Tarai of Nepal**. *Clim Dev* 2021, **13**:816–829.

54. Novotny I, Tittonell P, Fuentes-Ponce M, López-Ridaura S, Rossing W: **The importance of the traditional milpa in food security and nutritional self-sufficiency in the highlands of Oaxaca, Mexico**. *PLOS ONE* 2021, **16**:e0246281.

55. Son H, Kingsbury A, Hoa H: **Indigenous knowledge and the enhancement of community resilience to climate change in the Northern Mountainous Region of Vietnam.** *Sustain Food Syst* 2021, **45**:499–522.

56. Hosen N, Nakamura H, Hamzah A: **Adaptation to Climate Change: Does Traditional Ecological Knowledge Hold the Key?** *Sustainability* 2020, **12**:676.

57. Balehegn M, Balehey S, Fu C, Liang W: **Indigenous weather and climate forecasting knowledge among Afar pastoralists of north eastern Ethiopia: Role in adaptation to weather and climate variability.** *Pastoralism* 2019, **9**:8.

58. Mogomotsi P, Sekelemani A, Mogomotsi G: **Climate change adaptation strategies of small-scale farmers in Ngamiland East, Botswana**. *Climatic Change* 2020, **159**:441–460.

59. Radeny M, Desalegn A, Mubiru D, Kyazze F, Mahoo H, Recha J, et al.: **Indigenous knowledge for seasonal weather and climate forecasting across East Africa.** *Climatic Change* 2019, **156**:509–526.

60. Nkuba M, Chanda R, Mmopelwa G, Kato E, Mangheni M, Lesolle D: **Influence of Indigenous Knowledge and Scientific Climate Forecasts on Arable Farmers' Climate Adaptation Methods in the Rwenzori region, Western Uganda**. *Environ Manage* 2020, **65**:500–516.

61. Camacho-Villa T, Martinez-Cruz T, Ramírez-López A, Hoil-Tzuc M, Terán-Contreras S: **Mayan Traditional Knowledge on Weather Forecasting: Who Contributes to Whom in Coping With Climate Change?** *Front Sustain Food Syst* 2021, **5**:618453.

62. Ahmad Z, Rahman F, Dittmann A, Hussain K, Ihsanullah I: **Water crisis in the Eastern Hindu Kush: a micro-level study of community-based irrigation water management in the mountain village Kushum, Pakistan**. *Erdkunde* 2020, **74**:59–79.

63. Postigo J: **The role of social institutions in indigenous Andean Pastoralists' adaptation to climate-related water hazards**. *Climate Development* 2021, **13**:780–791.

64. Abeywardana N, Schütt B, Wagalawatta T, Bebermeier W: **Indigenous Agricultural Systems in the Dry Zone of Sri Lanka: Management Transformation Assessment and Sustainability.** *Sustainability* 2019, **11**:910.

65. Maikhuri R, Rawat L, Maletha A, Phondani P, Semwal R, Bahuguna Y, et al.: **Community Response and Adaptation to Climate Change in Central Himalaya, Uttarakhand, India**. In *Tropical Ecosystems: Structure, Functions and Challenges in the Face of Global Change*. Edited by Garkoti S, Van Bloem S, Fulé P, Semwal R. Springer; 2019:213–231.

66. Aniah P, Kaunza-Nu-Dem M, Ayembilla J: **Smallholder farmers' livelihood adaptation to climate variability and ecological changes in the savanna agro ecological zone of Ghana**. *Heliyon* 2019, **5**:e014922019.

67. Assefa Y, Yadav S, Mondal M, Bhattacharya J, Parvin R, Sarker S, et al.: **Crop diversification in rice-based systems in the polders of Bangladesh: Yield stability, profitability, and associated risk**. *Agric Syst* 2021, **187**:102986.

68. Van Huynh C, Phuong Le Q, Hong Nguyen M, Tran P, Nguyen T, Pham T, et al.: **Indigenous knowledge in relation to climate change: adaptation practices used by the Xo Dang people of central Vietnam.** *Heliyon* 2020, **6**:e05656.

69. Utete B, Phiri C, Mlambo SS, Muboko N, Fregene BT: **Vulnerability of fisherfolks and their perceptions towards climate change and its impacts on their livelihoods in a peri-urban lake system in Zimbabwe**. *Environment, Development and Sustainability* 2019, **21**:917–934.

70. Grey M: **Accessing seasonal weather forecasts and drought prediction information for rural households in Chirumhanzu district, Zimbabwe.** *Jamba J Disaster Risk Stud* 2019, **11**:1–9.

71. Ubisi N, Kolanisi U, Jiri O: **The Role of Indigenous Knowledge Systems in Rural Smallholder Farmers' Response to Climate Change: Case Study of Nkomazi Local Municipality, Mpumalanga, South Africa**. *Journal of Asian and African Studies* 2020, **55**:273–282.

72. Theodory T: **Understanding the relevance of indigenous knowledge on climate change adaptation among mixed farmers in the Ngono River Basin, Tanzania.** *Afr J Sci Technol Innov Dev* 2021, **13**:51–59.

73. **Pearson J, McNamara K, Nunn P: iTaukei Ways of Knowing and Managing Mangroves for Ecosystem-Based Adaptation. In *Managing Climate Change Adaptation in the Pacific Region*. Edited by Leal Filho W. Springer International Publishing; 2020:105–127.**

**Based on interview and participant observation data collected across six rural villages in western Vanua Levu, this study explores how iTaukei (Indigenous Fijian) communities have sustainably managed mangrove ecosystems over time and how this knowledge and experiences can enable future ecosystem-based adaptation options that are more sustainable and effective. The findings demonstrate the importance of understanding, respecting and utilizing Indigenous knowledge for local management and protecting ecosystems as part of communities' response to climate change adaptation.

74. Divine LM, Pearce T, Ford J, Solovyev B, Galappaththi EK, Bluhm B, Kaiser BA: **Protecting the future Arctic**. *One Earth* 2021, **4**:1649–1651.

75. Pauli N, Williams M, Henningsen S, Davies K, Chhom C, van Ogtrop F, et al.: **“Listening to the Sounds of the Water”: Bringing Together Local Knowledge and Biophysical Data to Understand Climate-Related Hazard Dynamics**. *Int J Disaster Risk Sci* 2021, **12**:326–340.

76. Ebhuoma E: **A framework for integrating scientific forecasts with indigenous systems of weather forecasting in southern Nigeria**. *Dev Pract* 2020, **30**:472–484.

77. **Lavoie A, Lee J, Sparks K, Hoseth G, Wise S: Engaging with Women’s Knowledge in Bristol Bay Fisheries through Oral History and Participatory Ethnography. *Fisheries* 2019, 44:331–337.**

**Based on the interviews with women engaged in salmon fisheries in Bristol Bay, Alaska, the study illustrates how oral history and participatory ethnography methods contribute to voices being heard that have been excluded from fisheries research and management. The study revealed that women’s knowledge might be critical in fisheries management decisions, community resilience, and socio-ecological sustainability in a region facing increased threats from climate change. Women shoulder major roles by contributing to the preservation of salmon fishing knowledge and cultural values through cross-generational knowledge transfer. Their participation in fisheries, deep knowledge of local resources, and education of the youth on the cultural value of fishing and the environment are critical to community socio-cultural and economic wellbeing.

78. Tilley A, Hunnam K, Mills D, Steenbergen D, Govan H, Alonso-Poblacion E, et al.: **Evaluating the Fit of Co-management for Small-Scale Fisheries Governance in Timor-Leste.** *Front Mar Sci* 2019, **6**:00392.

79. Islam M, Nahiduzzaman M, Wahab MA: **Fisheries co-management in hilsa shad sanctuaries of Bangladesh: Early experiences and implementation challenges.** *Marine Policy* 2020, **117**:103955.

80. Casagrande A, Salvatore R, Rover O, Chiodo E, Fantini A: **Artisanal mollusc fisheries co-management in Brazil and Italy: Institutional innovations to address environmental crisis**. *J Environ Manage* 2021, **291**:112671.

81. Suasi T, Koya I: **Strengthening the capacity of local communities for fostering community-based resources management/co-management: a case study in Khammouane Province, Lao PDR**. *Fish People* 2019, **17**:8–11.

82. Nguyen A, Hens L: **Diversified responses to contemporary pressures on sloping agricultural land: Thai farmer’s perception of mountainous landscapes in northern Vietnam.** *Environ Dev Sustain* 2021, **23**:5411–29.

83. Upadhaya K, Barik S, Kharbhih V, Nongbri G, Debnath G, Gupta A, et al.: **Traditional bun shifting cultivation practice in Meghalaya, Northeast India.** *Energy Ecol Environ* 2020, **5**:34–46.

84. Halkos G, Gkampoura E: **Where do we stand on the 17 Sustainable Development Goals? An overview on progress.** *Econ Anal Policy* 2020, **70**:94–122.

85. Moyer J, Hedden S: **Are we on the right path to achieve the sustainable development goals?** *World Development* 2020, **127**:104749.

86. Nyantakyi-Frimpong H: **What lies beneath: Climate change, land expropriation, and zaï agroecological innovations by smallholder farmers in Northern Ghana.** *Land Use Policy* 2020, **92**:104469.

87. de Scally D, Doberstein B: **Local knowledge in climate change adaptation in the Cook Islands.** *Local knowledge in climate change adaptation in the Cook Islands* 2022, **14**:360–373.

88. Magnan A, Schipper E, Burkett M, Bharwani S, Burton I, Eriksen S, Gemenne F, Schaar J, Ziervogel G: **Addressing the risk of maladaptation to climate change**. *Wiley Interdisciplinary Reviews: Climate Change* 2016, **7**:646–665.

89. Schipper E: **Maladaptation: When Adaptation to Climate Change Goes Very Wrong.** *One Earth* 2020, **3**:409–414.

90. Akinyi D, Ng'ang'a S, Girvetz E: **Trade-offs and synergies of climate change adaptation strategies among smallholder farmers in sub-Saharan Africa: A systematic review**. *Regional Sustainability* 2021, **2**:130–143.

91. Nykvist B, von Heland J: **Social-ecological memory as a source of general and specified resilience.** *Ecology and Society* 2014, **19**:26269552.

92. Tengö M, von Heland J: **Adaptive capacity of local indigenous institutions: the case of the taboo forests of southern Madagascar**. In *Adapting Institutions: Governance, Complexity and Social-Ecological Resilience*. Edited by Boyd E, Folke C. Cambridge University Press; 2011:37–74.

93. Armitage D, Berkes F, Dale A, Kocho-Schellenberg E: **Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic.** *Glob Environ Change* 2011, **21**:995–1004.