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Review Article

Traditional knowledge for climate change adaptation in Mesoamerica: A systematic review

Sofia Mardero [a], Birgit Schmook [b,*], Sophie Calmé [b,c], Rehema M. White [a], Juan Carlos Joo Chang [b], Grecia Casanova [b], Jorge Castelar [b]

[a] School of Geography and Sustainable Development, University of St Andrews, UK
[b] Department for the Observation and Study of the Land, Atmosphere and Ocean, El Colegio de la Frontera Sur, Ecosur, Mexico
[c] Department of Biology, Université de Sherbrooke, Canada

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ABSTRACT

Indigenous and rural peoples have developed close connections with land and nature for millennia. Traditional and local knowledge resulting from such human-environment interactions is embedded in ethnic, linguistic, and cultural contexts, and may assist local communities in adapting to global issues such as climate change. However, the extent to which traditional knowledge supports adaptation to local manifestations of severe socio-environmental changes, the traditional knowledge techniques that play an effective role in adaptation, and the dynamic yet integral aspect of traditional knowledge for indigenous and mestizo cultures remain unclear. Despite an extensive literature on climate change, adaptation, and traditional knowledge in the Global South, Mesoamerican countries are underrepresented. The aims of this systematic review were to address the main manifestations of climate change in Mesoamerican countries, to critically analyze relationships between traditional knowledge and contemporary climate change adaptation and to make recommendations regarding knowledge conservation, production, and exchange for climate change adaptation in the region. We systematically identified, reviewed, and coded 77 relevant papers. Our results show that: 1) most papers do not distinguish between local, traditional, and indigenous knowledge; 2) rainfall variability, droughts, and weather unpredictability are the most frequently expressed experiences of climate change; 3) the main adaptations undertaken by smallholders are changes to the agricultural calendar and crops cultivated, a shift to more sustainable agriculture, and labour diversification to generate off-farm income; and 4) many more articles are published on Mexico than the other Mesoamerican countries, and predominantly by authors from outside Mesoamerica. Local traditional knowledge makes important contributions to climate change actions and policy by observing changing climates, adapting to impacts, and contributing to global mitigation efforts. As a response to increasing climate change challenges, smallholders create new hybrid knowledge by combining traditional and western perspectives. This knowledge evolution will support greater resilience to climate change but may hasten cultural erosion and exacerbate social inequalities in the region unless efforts are taken to maintain cultural integrity.

1. Introduction

The effects of climate change in the tropics are expected to produce significant environmental changes (Sheldon, 2019), impacting the environment, health, wellbeing, and economic development of half of the planet's population by 2050 (State of the Tropics, 2020). Bridging two subcontinents and bordered by the Pacific and Atlantic oceans, Mesoamerica is one of the world regions most exposed to climate change, leaving its economically disadvantaged inhabitants and highly biodiverse ecosystems particularly vulnerable to its effects (Cifuentes Jara, 2010). Mesoamerica is a historical, cultural, and geo-economic region, which according to the geographical and cultural delimitation made by Paul Kirchhoff, spanned from central Mexico to the Pacific Coast of northern Costa Rica in pre-colonial times (Rovira Morgado,

* Corresponding author.
E-mail addresses: sm465@st-andrews.ac.uk (S. Mardero), bschmook@ecosur.mx (B. Schmook), sophie.calme@usherbrooke.ca (S. Calmé), rehema.white@st-andrews.ac.uk (R.M. White), juan.joo@ecosur.mx (J.C. Joo Chang), grecia.casanova@ecosur.mx (G. Casanova), jorge.castelar@ecosur.mx (J. Castelar).

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2007), including the Yucatan Peninsula, Guatemala, Belize, El Salvador, western Honduras, and the Pacific coast of Nicaragua (Nichols & Pool, 2012) (Fig. 1). Although its definition and delimitation have since been the subject of constant debate, it is still a widely used contemporary term. Mesoamerica, as used today, includes the southern part of Mexico and Central America and is an area of great topographic, climatic, ecological, and ethnic diversity. Mesoamerican people form an ethnic and linguistic mosaic that remains culturally visible and important today, including Mayas (present in almost the entire region) Aztecs, Teotihuacans, Zapotecs, Olmecs, Mixtecs, and Toltecs in Mexico (Rosenswig, 2009), Xincas in Guatemala and Salvador, Lencas in Salvador and Honduras, the Tawahkas in Honduras and Nicaragua, the Q'eqchi' Maya in Belize and Guatemala (Zarger, 2002) and many others. There have been, in some cases, forced resettlements, internal movements of people in search of better living opportunities, and partial assimilation with other ethnic groups, subsequently resulting in heterogeneous indigenous populations and communities whose knowledge is constantly adapting and evolving. This complex indigenous and mestizo (a term describing the blend of ethnicities, especially between Indigenous peoples and Spanish colonizers (Schwartz-Marín & Silva-Zolezzi, 2010)) assemblage has accumulated indigenous knowledge embedded in culture, responding to place, and underpinning traditional agricultural and foraging practices.

Traditional ways of life for many communities have been influenced, and threatened, by external factors, of which climate change is a dramatic and immediate example. Natural hazards in Mesoamerica include droughts, intense rains, floods, cyclones, increased temperatures, and changes in the timing of precipitation (UNFCCC, 2013). Average temperatures increased between 2011 and 2018, especially in the Yucatan Peninsula and the Central American dry corridor, by an alarming 0.59–1.05 °C. Further, three of these seven years included the strongest El Niño-Southern Oscillation (ENSO) events ever recorded. These temperature increases foreshadow conservative scenarios, which predicted increases of 0.8–1.6 °C for 2030 and 2.0–3.2 °C for 2080, in addition to growing rainfall variability, especially during the winter and early spring (ECLAC and CAC-SICA, 2020).

Rural farming communities, highly dependent on natural resources, are amongst the first to feel the effects of climate change (Soubry et al., 2020). Negative climate change impacts threaten the health, food security, and livelihoods of large rural populations in the tropics, including two-thirds of the world's poor (Randell & Gray, 2019). In Mesoamerica, climate change already negatively impacts millions of people in rural areas through higher drought frequency and water stress (Food and Agriculture Organization of the United Nations (FAO), 2020) that will likely increase in the future.

Climate change is primarily caused by industrial activities in other parts of the world, and yet the severe impacts of climate change in Mesoamerican countries are further aggravated by the prevailing socio-economic conditions in the region. According to Forbes Centroamerica (19/07/22) high poverty rates persist in most Mesoamerican countries. Overall rates soar in Honduras (73%) and Guatemala (60%), Nicaragua (52%) and reach almost 40% in Belize, 32% in Mexico (CONEVAL, 2021), and 23% in El Salvador. Such poverty means there is no or very little funding for disaster relief (e.g. after hurricanes) and for practical support of long-term adaptation to climate change. According to the World Food Programme (WFP), in 2019 2.2 million people in Guatemala, Honduras, El Salvador, and Nicaragua experienced crop failure due to excessive rain and droughts. In addition, recent aggravated violence and the COVID 19 pandemic have exacerbated the effects of years of drought, hurricanes and erratic weather for urban and rural communities in most Mesoamerican countries. These people have thus felt the brunt of the climate emergency, which has widely affected food production, especially of staple foods such as maize and beans, which are highly dependent on regular rainfall (World Food Program WFP, 23 February 20 21).

In Mesoamerica, agriculture originated with the *milpa*, a slash-and-burn shifting cultivation system, developed around 9000 years ago and characterized by the cultivation of corn, beans, squash, tubers, and many other crops, as well as fruit and timber species (Zizumbo-Villarreal & Colunga-García Marín, 2010). To date, *milpa* agriculture remains the most important smallholder farming system (Heinimann et al., 2017; Van Vliet et al., 2012) despite continuous initiatives to intensify smallholder agriculture by replacing the traditional polycultural *milpa* system with monocultures (Bray & Klepeis, 2005; Mardero et al., 2018). Despite adverse socio-economic conditions, the persistence of the *milpa* system across the varied climates of Mesoamerica's topography suggests that local farming communities have accumulated extensive knowledge of the local terrain and its biophysical patterns, as well as cultivation-specific knowledge such as seed varieties (e.g. Barrera-Bassols & Toledo, 2005). This 'treasure trove' of local knowledge, passed down from generations and social relationships, allows smallholders to adapt to a constantly changing environment over the long term (Arriens, 2019). However, in this review, we focus on contemporary, rapid climate change over the last 50 years.

Adaptive capacity is defined by the Intergovernmental Panel on Climate Change (IPCC) as the ''ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences'' (IPCC 2014, p. 182). It encapsulates not only the capacity to withstand and recover from current climatic hazards, but also to anticipate future changes (Granderson, 2017). For example, a range of adaptation measures can reduce vulnerability by lowering sensitivity or building adaptive capacity.

Despite evidence of some recent adaptations, indigenous and mestizo communities in Mesoamerica may have limited adaptation to climate change. Climate change impacts are further compounded by abrupt socio-political changes such as violent changes in political regimes, armed conflicts, economic crises, agrarian reforms, the neoliberal restructuring of economic policy with subsequent polarization, and social exclusion, followed by populist models and cash-transfer and welfare programs (Brachet-Marquez, 1992; Goma & Font, 1996). Such socio-political changes often result in loss of household income (e.g. Eakin, 2005) and can erode rather than strengthen knowledge of traditional agricultural techniques (e.g. Cálix de Dios et al., 2016). As such, it is important to support climate change adaptation of Mesoamerican communities through frameworks that facilitate the integrated scientific and local knowledge systems. Doing so will sustain and maintain cultural expressions evolved from continuous interaction with nature, local livelihoods, and long-term development opportunities (Karki et al., 2017).

The rapidity and extent of anthropogenic climate change are causing intense impacts on local places and people at a faster pace than traditional knowledge can adapt, such that additional knowledge systems must be integrated for survival (Alexander et al., 2011). Careful monitoring of agricultural systems' response to environmental change, experimentation with new (usually Western scientific) techniques, and improving old practices have together increased rural people's climate change knowledge and adaptation capacity (Soubry et al., 2020). Recognition of the contributions of traditional knowledge and knowledge integration to adaptation practices and culture is critical for policy practice and development.

From recognition of their importance to adaptation and sustainability research (IPCC, 2007) to the incorporation of best public policy practices (UNFCCC, 2013), local and traditional knowledge has become increasingly important for the global climate change adaptation agenda. As member parties of the United Nations Framework on Climate Change Convention (UNFCCC), it is compulsory for Mesoamerican countries to integrate local and traditional knowledge into national policies and programs. This integration has shifted the portrayal of local and traditional communities as victims, incapable of adapting to climate change (Caribbean Community Climate Change Centre (CCCCC) and Ministry of Forestry Fisheries and Sustainable Development (MFFSD), 2014; La Gaceta Diario Oficial (LGDO), 2019) to active agents who use local and

traditional knowledge to complement scientific knowledge in the search for climate change solutions (CNCC, 2016; INECC, 2018; Ministerio de Ambiente y Energía (MINA), 2018). Recognition of local and traditional knowledge is also essential for natural resource research and sustainable management programs that are embedded in adaptation and mitigation schemes (Ministerio de Medio Ambiente y Recursos Naturales de El Salvador (MARN), 2015). Worldwide, integration of local and traditional knowledge into National Climate Change and Adaptation Plans has been slow and irregular (Naess, 2013), with local communities only recently recognized as active players in local climate change action (Arriens, 2019; Soubry et al., 2020).

This systematic review critically analyzes the documented local and traditional knowledge used by smallholders in Mesoamerican countries in response to anthropogenic climate change, highlights challenges for knowledge production and integration, and provides recommendations for policy and practice in Mesoamerica and beyond. In doing so, we recognized the ambiguities around 'knowledge' and the complexities of the cultural context. Our research was guided by the following research questions: *1) How is climate change experienced by indigenous and mestizo smallholders in Mesoamerica? 2) What are the major climate change manifestations in the region? 3) How do individuals and communities respond to climate change? 4) What types of knowledge are involved in these responses? 5) What recommendations can we make regarding knowledge conservation, production and exchange for climate change adaptation in Mesoamerica and beyond?*

We addressed these questions through a systematic review of papers that examined the impacts of climate change on smallholders in Mesoamerica, their adaptation responses, and the knowledge sources driving these responses.

1.1. Theoretical framework

There are multiple, overlapping definitions for local, traditional, and indigenous knowledges (e.g. Aswani et al., 2018; Mantyka-Pringle et al., 2017; Sutherland et al., 2014). The term 'indigenous knowledge' has been widely used in development contexts and encompasses a spectrum of local and traditional knowledges, but is usually context specific (e.g. Sillitoe & Marzano, 2009). 'Traditional ecological knowledge' (TEK) was a term widely used in the 1980s. Later, Berkes (1993, p. 3) described TEK as "an approach that focuses on the conceptions of ecological relationships held by a people or a culture". It has been suggested that there are actually six components of TEK, including "factual observations, management systems, past and current land uses, ethics and values, culture and identity, and cosmology" (Houde, 2007). More recently, TEK has been associated with adaptation to environmental change at the household or community level (Naess, 2013). Indigenous and traditional ecological knowledges are dynamic and thus offer valuable and transformative knowledge bases for generating new and hybrid knowledge to address climate change in local communities (Naess, 2013; Sillitoe & Marzano, 2009). Given its dynamic nature, such knowledge is not only a robust data source in areas where scientific knowledge generation is still limited (Bocco & Winklerprins, 2016), but also can be a key to developing adaptation strategies to site-specific hazards that support local cultures and beliefs (Karki et al., 2017).

Not all local knowledge is framed by traditional or indigenous belief systems. In Mesoamerica, many regions are inhabited by diverse indigenous, displaced indigenous, traditional and modern settler groups, and thus it may be more appropriate to recognize the heterogeneity of such people and knowledge in the term "local and traditional knowledge", which includes indigenous knowledge (LTK – see also Aswani et al., 2018).

LTK for a long time was considered to be opposite to Western scientific knowledge (Mazzocchi, 2006), but a binary framing of LTK against Western scientific knowledge is inaccurate, as knowledge hybridizes (de Wit & Haines, 2022; Sillitoe & Marzano, 2009). However, there are concerns at the erosion of LTK through globalization, modernization, and market integration (Aswani et al., 2018), hence a focus on the origins, differences, and contributions of LTK is both valid and important.

At present, climate change mitigation and programmes for adaptation and resilience are believed to be mostly anchored in Western scientific knowledge (Makondo & Thomas, 2018). Western scientific knowledge can differ from LTK in that; 1) it often favors analytical and reductionist methods, 2) it is positivist and materialist, objective, and quantitative, and 3) it is based on an academic and literate transmission (Weiss et al., 2013). Western science often isolates its objects of study from their vital context by putting them in simplified and controllable experimental environments. In contrast, traditional knowledge is always grounded in specific contexts and particular local conditions (Nakashima & Roué, 2002) and is more holistic (Weiss et al., 2013). The distinction yet complementarity of both knowledge systems suggests that they should be further integrated through multiple evidence-based approaches for climate change adaptation and mitigation. Such knowledge is often not distinct from person and context, and "information" can be seen as an active "process of state change" (Casagrande, 1999).

The framing of LTK has differed across time and regions. In Latin America in the 1980s, the concept of "indigenous knowledge" appeared in scientific works from Mexico, Brazil, Bolivia, and Chile, shifting the focus from a highly input-depended agricultural production, boosted by the Green Revolution, to a more nature-grounded and smallholder-based agriculture (Kleiche-Dray & Waast, 2016). This interest stemmed from the Green Revolution's failure to alleviate poverty and hunger in a growing population, contributing instead to increased social inequality, concentration of production in big agribusiness, and negative impacts on human health and the environment (Kerr, 2012; Niazi, 2004; Pimentel & Pimentel, 1990).

In the 1980s, Hernández-Xolocotzi initiated the recognition of small farmers' knowledge in Mexico and started an agricultural research movement to raise awareness of the importance of studying traditional agrosystems. Other important agronomists followed suit in Mexico, such as Carlos Ortiz Solorio, who carried out work on agroecology and traditional knowledge in soil management (e.g. taxonomic evaluation of local land classification systems (1999)), and Alba Gonzalez with her work on the recovery of eroded soils, using the traditional knowledge of smallholders and traditional water management techniques (González-Jácome, 1999; 2003). In Chile, Miguel Altieri (1982) published "Agroecología: bases científicas de la agricultura alternativa" (Agroecology: the scientific basis of alternative agriculture), highlighting the importance of agroecology to support agricultural sustainability in Latin America. Simultaneously, other researchers focused on sustainable agricultural practices in Latin America, such as Robert Hart in Costa Rica, Ana Primavesi in Brazil, Juan Gasto in Chile, Mario Mejía in Colombia, and others (Altieri, 2015).

2. Methodology

2.1. Data collection

We conducted a systematic literature review because, unlike a narrative review, it calls for specific, structured questions, and is characterized by a predefined, rigorous, and systematic method (Higgins, 2011; Munn et al., 2018). A systematic review therefore provides robust findings from which conclusions can be drawn. We used the PRISMA method (Preferred Reporting Items for Systematic Reviews and Meta-Analyses; Moher et al., 2009) as a guide for this systematic review.

We searched for academic articles on climate change adaptation and TEK in Mesoamerica from 1998 (the year of first results) to 2020 using Web of Science (WoS), Google Scholar, and *La Red de Revistas Científicas de América Latina y el Caribe, España y Portugal* (The Network of Scientific Journals of Latin America and the Caribbean, Spain and Portugal (REDALyC)). We included articles with original case studies but also review papers and theses, because original case study articles in some

countries are scarce.

We determined the keywords for article selection following multiple search iterations of search term combinations and Boolean operators. Whilst we are cognizant of the cosmological depth of much LTK (see Houde, 2007), we focused primarily on applied contributions that might be integrated with Western scientific knowledge, and which offer immediate practical support to indigenous and mestizo peoples along with advice for policy makers. First, we included the term “Mesoamerica” in the search, but since this did not yield sufficient results, we then specified the names of each country in Mesoamerica. We searched in English and Spanish. In English, the terms “climate change” OR “precipitation variability” OR “drought” AND “traditional knowledge” OR “indigenous knowledge” OR “local knowledge” AND “adaptation” were first used for any part of the article, resulting in a large number of publications (e.g. 88,500 results for Mexico in Google Scholar alone). Subsequently, we limited our search to the title only. This resulted in 189 articles from Google Scholar and 259 from WoS. In Spanish, the terms “cambio climático" (climate change) OR “sequía" (drought) OR “var* precipitación" (precipitation variability) AND “conocimiento tradicional” (traditional knowledge) OR “conocimiento local” (local knowledge) OR “conocimiento indígena" (indigenous knowledge) AND “adaptación" (adaptation) were used for any part of the article and resulted in 263 publications.

Next, we narrowed down the number of publications. In a first step, only publications in which titles and abstracts mentioned climate change adaptation in rural communities by indigenous people or by smallholders were considered. Secondly, we discarded articles on climate change in urban settings, or the effects of climate change on flora, fauna, hydrology, palaeoclimate, and vulnerability indices. Further, we excluded articles from northern Mexico (which does not belong to Mesoamerica) and New Mexico, USA. After applying these filters, 106 publications remained, which were distributed to the authors for analysis. Articles were eliminated if 1) an article did not contain sufficient information to address the questions guiding this review (i.e. only providing answers to 1–2 research questions); 2) they dealt with case studies from several countries including some not located in Mesoamerica and the results were pooled, making it impossible to attribute findings to a specific country; and 3) they repeated the same data, for example, reviews with case studies where original research was already included in other articles selected for our review. After these steps, 77 articles were included in this systematic review.

Selection of key words always limits search outputs, and we are conscious of the constraints imposed in this review. First, by focusing our keywords on changes in precipitation and drought, we may have left out other effects of climate change. However, our choice was motivated by the large effect of these two variables as manifestations of climate change on rainfed traditional agriculture (Harvey et al., 2018; Kinda & Badolo, 2019; Mardero et al., 2015). Second, the word "knowledge” (local, indigenous, or traditional) was central to our search, and we may therefore have overlooked publications that also addressed this issue but did not use the term “knowledge”. Third, the large number of articles on Mexico compared to the other Mesoamerican countries makes country comparison difficult.

2.2. Data analysis

Coded data from the selected articles were transferred to an Excel spreadsheet. To ensure internal consistency of the extracted information, 10% of the articles were cross-checked by one of the two first authors through independent reading and code allocation. The spreadsheet included the search tool, year of publication, journal name, country of first author, whether at least one of the co-authors was from the country where the research was conducted, country where the research was conducted, study site climate type, form of publication, research objective, methodology used, and the following open-ended categories to address the research questions:

- *Observed changes in climate:* General unfavorable climatic features, as perceived by the respondents who participated in the article’s case studies.
- *Causes of climate change:* The causes associated by respondents with observed changes in climate.
- *Main effects of climate change:* A list of impacts that observed climate changes have had on the environment, agriculture, and on smallholders’ economic activities and livelihoods.
- *Responses and adaptations:* All actions taken in response to the effects of observed climate change.
- *Knowledge sources for responses made:* While we intended to distinguish types of knowledge (traditional, local, indigenous and Western scientific knowledge) that indigenous and mestizo smallholders use to respond and adapt to climate change, we were unable to do so as most reviewed publications did not distinguish between knowledge types and definitions varied. We thus refer to LTK, defining it here as ‘knowledge held and applied by local smallholders and indigenous people in social and physical processes to respond to climate change and usually in association with traditional ways of being and living’. In this, we draw on the TEK and Local Ecological Knowledge definitions of Berke et al. (2000), where TEK is grounded in environmental relations, and has factual, practical, and ontological aspects (Houde, 2007). Local Ecological Knowledge is defined as the knowledge of local smallholders, who may not be indigenous, and who may be relatively moved to the area (Aswani et al., 2018). In several reviewed publications, the authors did not specify if smallholders’ adaptations resulted from TEK, and only referred generically to smallholders’ knowledge. We therefore decided to employ the term ‘LTK’ for cases in which we identified the knowledge used to adapt to climate changes to be grounded in LTK, whether explicitly mentioned or not by the publication’s authors. We identified ‘Western scientific knowledge’ as scientific, globally disseminated knowledge generated through research, or via government, non-governmental organization or educational network sources. We used ‘LTK & Western scientific knowledge’ in cases where community adaptation responses were grounded in LTK, but were also partially based in Western scientific knowledge. ‘Western scientific knowledge only’ was used when adaptation responses resulted solely from this knowledge source. Where there was any ambiguity, we consulted across authors to ensure consistency of allocation. Our review includes research contributed by academics, government programs, and non-governmental organizations.

We grouped the 77 papers into two categories, Mexico and Central American Countries, because many more articles were published about Mexico than about all the other countries combined. By doing so, we avoided statistically invalid comparisons among countries with large differences in the numbers of published articles. Another argument for the division into these two categories is the fact that the Central American countries have greater geographic, social and cultural similarities among themselves than with Mexico.

3. Results

Since the first publication for this review in 1998, the annual number of papers varied with a remarkable increase since 2013. Of the 77 articles reviewed, 71% (N = 55) were based on original case studies, six were review articles, and five combined case studies and an extensive literature review. The rest of the reviewed materials (N = 11) included theses and reports (Fig. 1a). In half of the papers (N = 39), authors employed qualitative methods such as semi-structured interviews, focus groups and workshops, followed by mixed methods (N = 33). In only five cases did the authors solely rely on quantitative methods (surveys, modeling, projections) (Fig. 1b).

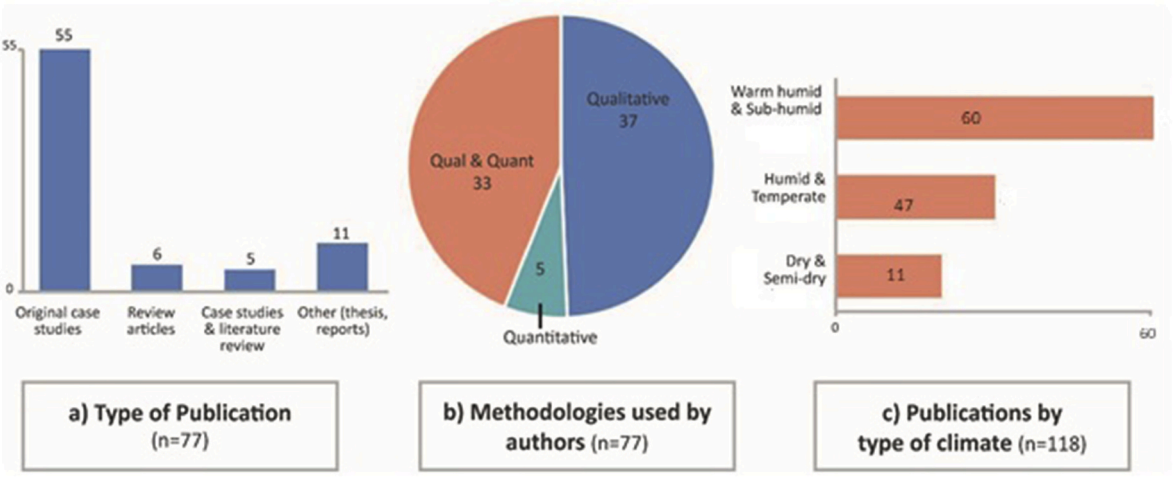

Fig. 1. Characteristics of reviewed papers by a) type of publication; b) methodology used by the authors; and c) type of climate.
In graph c) the values exceed 77 because some publications dealt with study areas encompassing several climate types.

We also classified the publications by climate type (based on Köppen's climate classification) (Fig. 1c). As some papers included several geographical areas with different climate types, the number of responses added up to 109. Of these, 77% (N = 60) originated in regions with a Warm Humid and Subhumid climate (group A), either with summer (Aw) or year-round rainfall (Am). Forty-one (16%) of the papers reported research from Humid Temperate climates (C), and only eight papers from the Dry and Semi-dry climate (group B). These results may reflect the fact that most of Mesoamerica is dominated by climates A and C, or it could be due to more indigenous people living in these climate zones.

3.1. Climate changes experienced

This review found that smallholders in Mesoamerica mainly associate climate change with rainfall variability. Expressions such as "atypical", "random", "distorted patterns" "uncertainty", "irregular", "unpredictability", "increasingly unstable", "erratic", were frequently used to describe precipitation behavior over the last decades. Precipitation variability also includes extreme wet and dry events, such as floods and droughts, which were also widely mentioned by smallholders. Another commonly noted manifestation of climate change was a rise in temperature (Fig. 2a). In addition to showing the manifestations of climate change mentioned in the reviewed articles (a), Fig. 2 also shows the causes associated with these changes (b) and the main effects that these changes have had on the rural environment (c).

Rainfall variability often followed an overall decrease in rainfall and an increase in drought frequency/severity. Increased temperatures were also reported as one of the main changes in climate and mentioned in around half of the papers (N = 37 (48%)) (Fig. 2a). In a Mexican study (Bocco et al., 2019), smallholders indicated that the climate had changed significantly in recent decades compared to what they had heard from their elders, creating a sense of uncertainty about the prospects for upcoming agricultural cycles. In some publications, however, we could not determine whether respondents associated these climatic features with recent climate change or whether they had always been observed through cyclical climate changes at the study sites.

3.2. Causes of climate change

The causes of climate change were reported in only 26 articles. The most frequently mentioned causes of climate change were deforestation

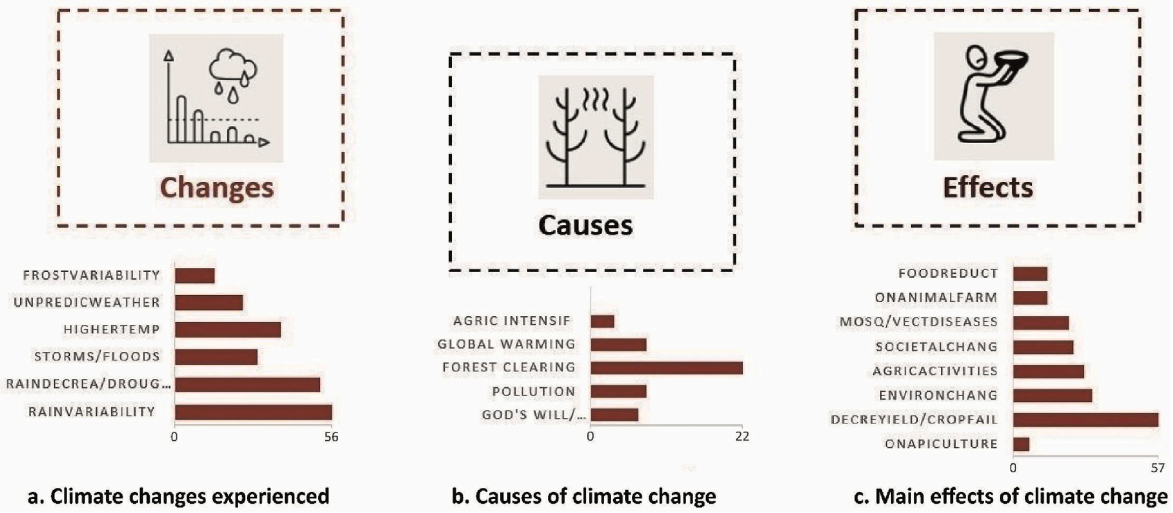

Fig. 2. a) climate change manifestations, b) causes of changes and c) main effects of climate change. The horizontal bars indicate the number of articles mentioning each type of climate change, cause, and effect.
The value of *n* varies across graphs a, b and c according to the number of publications that gave answers to those questions.

(mentioned in 19 papers), pollution and global warming and ENSO (each found in 7 papers), and causes related to divine punishment (6 papers) (Fig. 2b). Barrasa Garcia's (2017) research in Chiapas, Mexico, found that in some indigenous communities, climate change and its consequences are seen as a punishment by the guardians of the forest. The same phenomenon is reported from indigenous communities in Oaxaca, and, according to Mathews (2009), seen as a divine punishment for cutting down forest.

3.3. Effects of climate change

Climate change is already putting significant pressures on smallholder agriculture across Mesoamerica. Fig. 2c shows that in more than 80% of papers reviewed, changing precipitation patterns and rising temperatures are causing crop failures and severely reducing crop yields (55 of the 66). Several publications addressed the impact of climate change on maize harvests, documenting declines in the area cultivated, decisions to skip planting in the spring-summer cycle to exclusively plant in the winter, or entirely/fully abandoning maize cultivation (Aguilar et al., 2009; Eakin et al., 2018; Soares and Sandoval-Ayala, 2016; Orozco-Ramírez et al., 2020 among others). Impacts on coffee have also been widely recorded, with various authors (Rice, 2018; Ruiz-Meza, 2015; Villarreal, 2018) mentioning that torrential rains cause flowers and seeds to drop, that high temperatures lead to more coffee pests, and that coffee plants need to be established at higher altitudes, subsequently causing deforestation, among other problems.

Negative climate change impacts on pest and disease incidence (19 publications), on beekeeping (6 publications), and on livestock (9 publications) were also reported, with serious consequences such as reduced food production and decreases in household income. Adverse effects on beekeeping have been reported in relation to the drought's impact to flowering and the devastating impact of hurricanes on bee food resources (López-Barrios et al., 2019; Metcalfe et al., 2020). Although some authors (Audefroy and Cabrera Sánchez, 2017; Rodriguez-Solorzano, 2014) suggested that livestock are less vulnerable and sometimes even used as a strategy to cope with extreme weather events, others considered that droughts significantly affect livestock feeding, health, and reproduction (Metcalfe et al., 2020; Rogé and Astier, 2015). Changes in environmental characteristics (such as soil erosion, drying of water bodies, changes in water quality, among others) were also reported in 30 publications. Social changes usually associated with low rural agricultural productivity (such as migration and labor diversification) were reported in all Mesoamerican countries (19 articles). According to Bocco et al. (2019), climate variability has also led to the loss of traditional weather forecasting knowledge and techniques used by smallholders for generations, as weather has become unpredictable.

3.4. Responses and adaptations to climate change

The main responses and adaptations to climate change in agriculture as documented in the literature reviewed are shown in Fig. 3. This review found that the most common responses were changes in agricultural practices, ranging from altered agricultural calendars to new crops and reseeding practices after agricultural disasters (in 49 of the 70 articles). Our review also highlighted other important adaptations, including more sustainable agricultural practices (44 papers). For example, smallholders in Guatemala, Honduras, and Mexico reported planting shade trees and adopting more sustainable soil management and conservation practices (Alpzar et al., 2020). In the Mixteca Alta, Oaxaca, smallholders practice terraced agriculture that actively prevents soil erosion (Bocco et al., 2019). Sustainable practices were also described by authors writing about other countries (e.g. Bocco et al., 2019; Rice, 2018; Sousa et al., 2018; Villarreal, 2018). Silvopastoral systems were also reported in Mesoamerican countries (e.g. Baha-l'okwibale et al., 2018; Metcalfe et al., 2020). Conversely, agricultural intensification, which is accompanied by increased use of agrochemicals

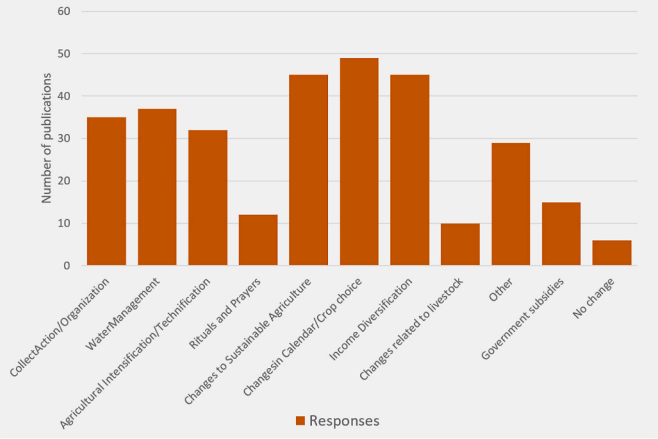

Fig. 3. Responses and adaptations to climate change in agriculture as documented in the literature reviewed.
The sum of all values will not add up to 70 because most of publications mentioned more than one adaptation strategy.

(noted in 32 papers) and water management/irrigation systems (37 papers), were reported. These longer-term responses to more socio-economic or political drivers (i.e. reduced availability of land and the resulting reduction in fallow periods) are often supported by public investment, policy changes, and other strategies to promote adaptation. For example, some Mexican agricultural programs only provide support for agricultural inputs on permanently tilledagricultural parcels to avoid land clearing. Finally, diversification of economic activities (noted in 45 papers) was the second most named strategy. It allows smallholders to reduce climate hazards, but sometimes risks smallholders abandoning food production.

Collective organization and action, through cooperatives, for example, is also viewed as an important response to strengthen smallholders' capacities to face climate change in almost half of the articles analyzed (35 papers). In Michoacan, Mexico, for example, Campos et al. (2014b) documented that smallholders form strong family ties and social networks to ensure community development and identity. Indigenous traditions are still important in Mesoamerican countries for climate change responses and risk management strategies. Rituals and prayers that follow the agricultural calendar to invoke rain and good harvests continue to play an important role. This is evidenced by the fact that 7 articles mention smallholders organizing prayers, offerings, and rituals to ask for good harvests. As Kernecker and colleagues (2017) reported, in Mexico the local tradition to pray and to place offerings to San Isidro in times of scarce or excessive rainfall, is widely used. The Mazahua natives in Mexico still hold traditional celebrations from May to June to ask for rain (González et al., 2017). However, there was no mention of whether these practices have changed recently due to climate change. Segnestam (2017) recorded that in Nicaragua women pray first to God to help them survive droughts, which the author interprets as an expression of the women's perception that they themselves are unable to change anything about their situation except to pray and endure. Recourse to government programs and support is another response to the impacts of climate change on agriculture, particularly in Mexico, where more than half of these cases have been reported (9 of 16). In Mexico, the government spent 20 billion United State dollars (USD) in direct payments to farmers during 1994–2009 (Fox & Haight, 2010), and continues to rely on direct payments, training, agrochemical delivery programs, payments in case of harvest losses and more. Smallholders are continuously taking measures to adapt to the new climatic conditions, whether through on-farm or off-farm activities, or a combination of both, as evidenced by most of the contributions. This is underscored by the fact that only 7 of the publications studied found that smallholders had done nothing or implemented no adaptation strategies.

Fig. 4 shows the adaptation strategies of smallholders in Mexico and Central America, identified in the reviewed literature. We found no differences between those in Mexico and those in Central America (Fig. 4). The adaptations most often mentioned were sustainable agricultural practices (80% of 31 papers from Central America, and 62% of 57 papers from Mexico). Income diversification was another frequently reported strategy, both for Mexico (47% of the 57 papers) and Central America (58% of the 31 papers). Adaptation measures manifested in changes in the agricultural calendar and crops grown, and were mentioned in almost 60% of papers, both for Mexico (34 papers) and Central America (18 papers). Water management and collective action or social organization were also prevalent adaptation measures in Mexico and Central America.

3.5. Knowledge sources of adaptation responses

Local and traditional knowledge continues to play an important role in smallholder adaptation to climate change in Mesoamerica. This can be seen in Fig. 5, which shows the sources of knowledge for the different adaptation strategies in Mexico and Central America. It is especially important in Central American countries, where it is mentioned in 83% of all contributions. In Mexico, although still important, it is noted less with a slightly lower importance (59%). Combining local and traditional knowledge with Western scientific knowledge is recorded less frequently, but is of increasing importance for both Central America (52% of papers) and Mexico (33% of papers). For some case studies on Mexico (10%) adaptations are reported to be based solely on Western scientific knowledge (see Fig. 5).

The increasing interactions of traditional and Western scientific knowledges were mentioned in several articles with examples from several countries. In Guatemala, Ramírez Maradiaga et al. (2015) suggested that the interaction of indigenous and mestizo people and technical professionals from the program *Kuxur Rum* created an alternative technology based on ancient knowledge, making use of multipurpose native trees from the dry forest. Local smallholders named the practice *kuxur rum* meaning "my humid land" in Ch'orti. Mercer and colleagues (2012) in Mexico showed that smallholders have deep knowledge on how to select landraces adapted to specific local conditions. The authors define a "landrace" as a domesticated, locally adapted, traditional variety of animal or plant species. They warned, however, that climate change could happen so rapidly that smallholders would no longer be able to select for desired adaptive traits, causing the disappearance of many landraces. In Mexico several communities have a trusting relationship with local non-governmental organizations and habitually rely on them to support environmental projects and activities in their communities. In indigenous communities, non-governmental organizations and environmental organizations can play an important role in raising

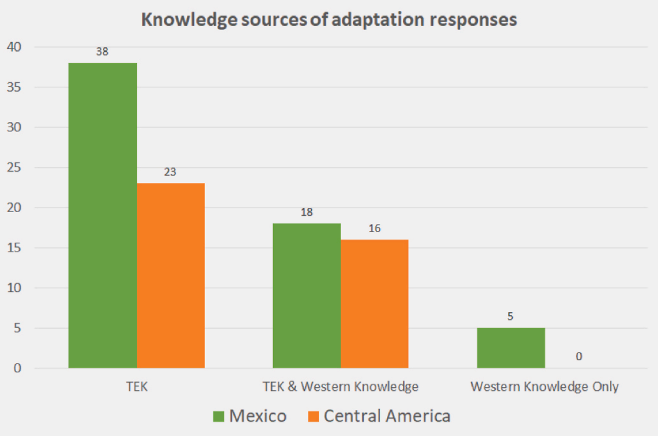

Fig. 5. Sources of knowledge for adaptation strategies in Mexico and Central America.
Values will not add up to the total of $n = 54$ (México) and $n = 31$ (Central America) (number of publications that addressed knowledge), because some publications include two or more countries, and there may be more than one source of knowledge in each document.

concern and awareness about climate change. They can support successful coping strategies that are proposed by government and academia (Ambrosio-Albala & Delgado-Serrano, 2018). In Nicaragua, smallholders are implementing adaptation measures acquired through local knowledge that they pass on and share amongst themselves, but also through Western scientific knowledge (introduced by governmental and non-governmental organizations), as outlined by Bro and colleagues (2020).

3.6. Who publishes on rural climate change adaptation in Mesoamerica?

Eighty percent (62 out of 77) of the articles included in this review were published in English, despite Spanish being the most widely spoken language in the region. As can be seen in Fig. 6, the number of publications for each of the studied countries differed greatly, ranging from 63 (82%) publications on Mexico to only two on Belize and Costa Rica. In 50% of the 63 articles covering Mexico, the corresponding author was affiliated with a Mexican institution. This was very different from the other Mesoamerican countries, where in 30 of 32 articles the corresponding author was affiliated with a foreign institution, predominantly the United States.

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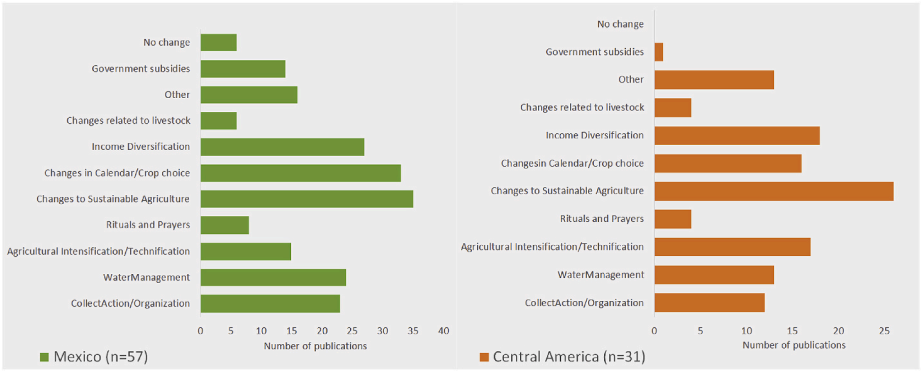

Fig. 4. Identified adaptation strategies and their frequency in the Mexican and Central American studies.
The sum of the values will not add up to 57 (Mexico) and 31 (Central America) because many publications mentioned more than one adaptation strategy.

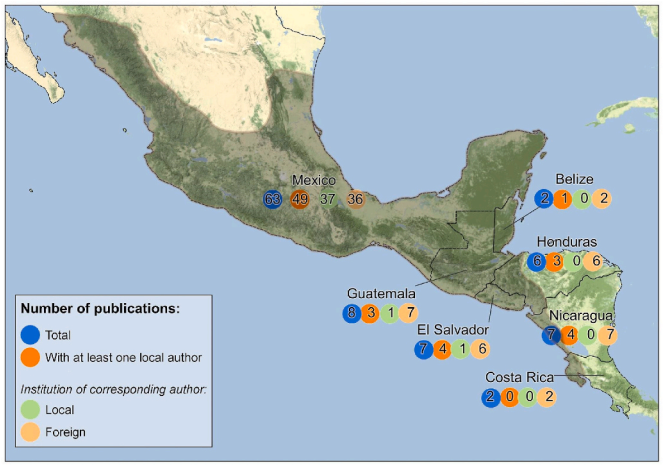

Fig. 6. Number of publications by country, and representation of local and foreign corresponding authors in publications.
Source: Nichols & Pool, 2012. *The Oxford Handbook of Mesoamerican archaeology*.
The shaded area represents Mesoamerica.

4. Discussion

4.1. Experiences of climate change and its main effects on agriculture

Smallholders are keenly aware of changing climatic conditions, because they plan their planting, management, and harvesting activities in response to seasonal rainfall patterns (Bacon et al., 2017; Eakin, 2000). Smallholders also see the visible impacts of extreme temperatures, droughts, or torrential rains on plant growth, flowering, and pest and disease incidence (Cruz-Bello et al., 2011; Philpott et al., 2008). As outlined by Metcalfe and colleagues (2020), changes in *el tiempo* (weather) in southeast Mexico are generally recognized by smallholders, though not expressed as "climate change". Further, the way they perceive these changes affects the acceptance and application of traditional weather knowledge and cultural practices (e.g., Kalanda-Joshua et al., 2011; Pepin, 1996; Sánchez-Cortés & Lazos-Chavero, 2011).

Rainfall variability and droughts are not the only climatic anomalies recognized (and suffered) by Mesoamerican smallholders. Rising temperatures were reported in half of the articles reviewed and addressed by multiple reports (Economic Commission for Latin America and the Caribbean (ECLAC) et al., 2015; IPCC, 2018; World Wildlife Fund for Nature (WWF), 2020). Mesoamerican smallholders' perceptions of extreme climate change and great uncertainty seems fully justified when examining the Global Climate Risk Index from 2004 to 2013, with most of the Mesoamerican countries ranked in the top ten positions: the first place worldwide was held by Honduras, Nicaragua fourth, Guatemala ninth, El Salvador twelfth, Costa Rica sixteenth, and Belize twenty-first. Our review indicates that these climatic changes are already putting significant pressure on smallholder agriculture across Mesoamerica, and highlights the urgent need to support adaptation measures and enhance resilience to ensure food security and maintain rural livelihoods under changing climatic conditions.

Traditionally, smallholders in this region have led subsistence livelihoods in which they practice *milpa* agriculture, a polycultural system with an integrated approach to agriculture and forest management (Zizumbo-Villarreal & Colunga-García Marín, 2010). Despite development efforts to support more commercial, intensive forms of agriculture such as ranching and monocultures, *milpa* cultivation, adapted to poor soil conditions and rainfed cultivation, has remained strong in the region (Mardero et al., 2018). *Milpa* is also strongly linked to culture, identity, and food sovereignty (see La Via Campesina for more information on the importance of the *milpa*). Hence, whilst there is clearly a need to provide additional knowledge and techniques to support smallholders to navigate climate change effects, it is important that this support acknowledges people's cultural identities. Such acknowledgment would also facilitate the uptake or integration of new techniques and knowledge.

4.2. Adaptation responses to climate change and sources of knowledge involved

Indigenous and local people have, collectively or individually, long relied on traditional knowledge to adapt to changing economic, ecological, and social conditions (Anik & Khan, 2012). Our review shows that, in the Mesoamerican countries, traditional knowledge still provides a crucial foundation for community-based adaptations that may help to sustain the resilience of social-ecological systems at different scales. Adaptation and resilience in the face of change are embedded in traditional knowledge, diversified resources and livelihoods, social institutions and networks, and cultural values and attitudes (Raygorodetsky, 2020). However, indigenous and local peoples often continue to be excluded from the global processes of decision and policymaking that define their future (Soares et al., 2014).

Recent climate change calls for very rapid adaptation measures (Galloway, 2012; Naess, 2013). Many indigenous and non-indigenous smallholders recognize that their accumulated knowledge is less effective in the face of increasingly severe and rapid weather changes. As the weather changes more dramatically each year, predictions based on traditional knowledge are becoming less reliable for making decisions about agricultural activities (Infante Ramírez & Arce Ibarra, 2019). Smallholders are also facing additional issues, such as land tenure challenges, which further complicate local adaptation responses to and effective policy responses for climate change (Murken & Gornott, 2022). So what happens when traditional knowledge is no longer sufficient to provide tools for smallholders to adapt to climate change? Short-term adaptation activities might be underway, but long term and successful adaptation requires financial, human and technological resources and capacity development (Khan et al., 2013) which most poor indigenous and non-indigenous communities do not have and which are not easily accessible.

The challenges of managing adaptation measures to changing climate, socio-economic conditions, and policy development stimuli could lead to the abandonment of agricultural activities (deagrarization) in some regions (Hebinck, 2018). It is therefore not surprising that around half of the reviewed articles noted that smallholders diversified their livelihood strategy to incorporate more off-farm activities. This combination of changes in agricultural practices and labor diversification is neither new nor specific to Mesoamerica. Similar responses have been documented from other parts of the world, for example in Africa (Akinnagbe & Irohibe, 2014; Wuepper et al., 2018), Asia (Jat et al., 2016), and Europe (Reidsma et al., 2010). Government subsidies play an important role for the survival of smallholders, especially in Mexico (Mardero et al., 2020). However, opponents of agricultural subsidies argue that government transfers weaken smallholders' adaptive capacities, and make them dependent and vulnerable, while at the same time supporting industrial agricultural production of cash crops like corn, soybeans, and wheat (Searchinger et al., 2020). Our review suggests that the situation is more nuanced than either of these perspectives. Traditional knowledge alone seems to be insufficient to enable Mesoamerican smallholders to adapt to the climate changes effects mostly caused by the Global North, signifying that some support is required to provide the technical and capacity resources needed (Khan et al., 2013). However, support that emphasizes technical agricultural intensification at the expense of traditional knowledge may exacerbate inequalities and contribute to erosion of cultural and place-based identities. We suggest that careful consideration be given to provide agricultural support sensitive to cultural context and which respects sustainable and local agroecological practices. As Schmook et al. (2022) point out, previous experiences with an uneven expansion of modern technocentric

agriculture, fueled by the model of the Green Revolution, have been implicated in the ongoing marginalization of smallholders. This experience should not be forgotten. Smallholders' ideas and desires have often been conditioned to believe in improved agricultural practices linked to the need to access hybrid seeds, chemical inputs, and technical extension, at the expense of traditional knowledge.

Our review identified that shifts towards sustainable agricultural practices have already occurred in Mesoamerica, such as documented cases of successful sustainable agriculture projects in organic coffee plantations in Guatemala, El Salvador and Nicaragua (Kilian et al., 2006; Méndez et al., 2017) as well as in Mexico (Pérez Akaki, 2009). However, in Mexico, government subsidies for rural and social assistance play a more important role on smallholder's responses to climate change (González-Estrada & Orrantia-Bustos, 2006). Given the socially-embedded context of traditional knowledge (Audefroy and Cabrera Sánchez, 2017; Karki et al., 2017) and the power inequalities across some knowledge forms (Nygren, 1999), it is necessary to explore such integrated approaches within the framing of both transnational agrarian movements and local smallholder needs (Boyer, 2010).

4.3. Local and traditional knowledge and climate change

Our review provided important insights on 'knowledge'. While 'scientific knowledge' is generally understood to involve Western technology or techniques, there exists no concise definition of 'traditional knowledge' (Galloway, 2012; Sillitoe, 1998). In Western cultures, knowledge (in particular scientific knowledge) is presented in opposition to practice, and the rational is presented in opposition to the spiritual (i.e. science vs religion). In indigenous worldviews, however, these elements are usually combined in a holistic understanding of interaction with the surrounding environment (Galloway, 2012; Nakashima & Roué, 2002).

In our review, we included a range of search terms relating to traditional knowledge and found that multiple terms are often used in the same paper (e.g. indigenous, traditional, and local knowledge) and interchangeably. Determining what the authors meant by the knowledge term they used was difficult, as a definition of the knowledge discussed was provided in less than 20% of articles reviewed. It is possible that definitions differ across regions, or that researchers accept fluidity and overlaps across these terms (Mantyka-Pringle et al., 2017; Sutherland et al., 2014). Such authors thus highlight how people use and refer to their own knowledge base, for example, techniques they learned from their elders, but do not engage in epistemological and ontological reflections on knowledge. This reflects the approach taken in IPCC reports, where a distinction between different forms of knowledge is avoided (e.g. Field et al., 2014). Although we concur that LTK, like TEK, has different aspects including management systems, culture and identity, and cosmology (Houde, 2007), it seems that most research on climate change adaptation has focused on technical management solutions rather than ontological underpinning.

A growing body of literature has emphasized the importance of incorporating traditional knowledge and practices into development and conservation projects since the 1970s (Gómez-Baggethun et al., 2013; Mercer et al., 2009; Ramos, 2018; Tang & Gavin, 2016), and more recently, to overcome the effects of climate change, environmental hazards and disasters (Cronin et al., 2004; Dekens, 2007; Haynes, 2005; Mitchell & Sackney, 2006). This importance was reflected in the more than 18,000 results obtained on Google Scholar using the string of words "indigenous, local and traditional knowledge for climate change adaptation". Nevertheless, the preservation of this knowledge, not only in Mesoamerica, but in all countries, is under threat (Turner & Turner, 2008). In the face of profound and ongoing environmental changes, both cultural and ecological diversity are likely to be severely impacted, along with a reduction in local resilience capacity (Aswani et al., 2018; Kelly, 2005).

While traditional knowledge is dynamic and continually influenced by internal innovation and experimentation involving local culture, ethos and values, and by interactions with external systems and outside knowledge, the overall global trend indicates a considerable loss of inter-generational cumulative environmental knowledge (Godoy, 1994; Gómez-Baggethun et al., 2013; Ingold, 2000). As anthropogenic climate change is a relatively recent phenomenon, indigenous communities have little experience integrating their knowledge into modern climate-change adaptation processes (UNFCCC, 2013). This led some scientists to conclude that while traditional knowledge and practices could be used as a starting point for adaptation-related decision-making, hybridization with western knowledge is fundamental to achieving greater smallholder agricultural resilience (Bhatia et al., 2014; Cox, 2000). As our results show, combining traditional knowledge with western knowledge is emerging as a popular strategy for adaptation to climate change, highlighted in 41% (N = 77) of the articles reviewed. Knowledge is already being hybridized through new forms of information or its exposure to external socio-economic drivers (Gómez-Baggethun et al., 2013).

Although some authors report that local and traditional knowledge systems are disappearing (Cox, 2000; Gómez-Baggethun, 2009), academic understanding of traditional knowledge has become more sophisticated through increasing recognition of its dynamic nature. This review thus identifies a potential paradox. Should traditional knowledge be preserved as it is, with only incremental change made, within communities? Or should we promote the integration of scientific (western) and traditional knowledges, with external input? In response to this we suggest, first, that the boundaries between scientific and traditional knowledge should be understood as less rigid to facilitate a move from the traditional knowledge (sustainability panacea) and scientific (western) knowledge (development scapegoat) dichotomy to a notion of heterogeneous, 'situated knowledge' (Nygren, 1999). Second, Nygren (1999) also points out that the implementation of knowledge is influenced by sophisticated power relations. Hence, any attempt to integrate forms or sources of knowledge need to include recognition of possible power asymmetry and genuine partnership between external agencies and local communities. Finally, many of the papers reviewed highlighted how collective action and cooperatives offered an adaptation response. We suggest that (traditional) knowledge thus be seen not only as the attribute of an individual or even household, but that it be seen as a shared, collective factor that is dependent on community form, context and relationships.

4.4. What recommendations can we make regarding knowledge conservation, production and exchange for climate change adaptation in Mesoamerica?

Our systematic review supports several recommendations. We are concerned about the need for climate change adaptation by indigenous and local people in Mesoamerica; about the loss or erosion of local and traditional knowledge systems; and about the current research system. The inclusion of LTK is essential in efforts by and for indigenous and local peoples to survive the effects of climate change, but paradoxically this inclusion will not be possible unless we can strengthen relationships and trust between such people and practitioners, policy makers, and researchers to enable mutual understanding and knowledge integration (Whyte, 2018). This requires not only research investment, but also support of gatekeepers who can facilitate such relationship building.

First, we thus suggest that funders, institutions, and academics support additional funding in this area, particularly in diverse countries. Two thirds of the review publications focused on Mexico, possibly reflecting differences in education and research investment between Mexico and Central America (García Zamora, 2012), but thus missing potential contributions from elsewhere. Secondly, we plead for more research by, and collaboration with, Central American researchers. Almost all of the Central American publications were led and co-led by researchers from institutions in the Global North, mainly from the

United States. Lead authors on smallholder dynamics in Global South are often from the Global North (Aswani et al., 2018; Shaffril et al., 2020; Soubry et al., 2020). Local researchers may have more input to policy and decision making and also may embed and negotiate different knowledge aspects, such as ontological plurality along with technical adaptations. However, we also recognize the importance of international research movement and collaborations. For example, Mesoamerican nationals can work from other countries (as is the case of the lead author on this paper). Such individuals can play a critical role in studying knowledge systems; if knowledge is situated within people and roles (Nygren, 1999), they can transcend some of the epistemological barriers whilst accessing international resources. Third, we promote more publications in Spanish to engage local audiences. Publication in English is common even by native Spanish speakers to communicate their results to the international scientific community, to have their research recognized more widely, to meet the requirements for professional promotion (López-Navarro et al., 2015), and for international funding requirements (Iwama et al., 2021). However, there is a risk that exploration of LTK systems through a Western knowledge prism reduces ontological plurality and reinforces reductionist and analytical approaches to forms of knowledge embedded in cultural beliefs (Mazzocchi, 2006). As digital translation media are improved, accessibility for different publications may emerge. Given the prominence of Mexican researchers in this field, there is potential for Mexico to play a leading role in supporting and collaborating with neighboring academics and institutions. Fourth, we promote wider engagement with the 'ecosystem of expertise' (Brand & Karvonen, 2007) to link research findings to policy and practice, co-design and co-production participatory approaches, and provisioning of a range of locally relevant output forms. With these recommendations comes the idea that communities must not be left to adapt to climate change alone; structural changes at international and national levels are also needed to address this global challenge (Meyerricks & White, 2021). These authors argue for systemic change, including shifts in policy, technology, and leadership, to catalyse a sustainability transition, address structural inequalities and prevent community action from being only marginal or liminal. Addressing climate constraints requires far-reaching structural transformation of productive activities, where a climate-conscious structural transformation must include a global shift from high-to low-carbon intensive activities (United Nations Conference on Trade and Development UNCTAD, 2021). In addition, structural and institutional changes must involve a meaningful shift towards an economy that centres wellbeing, framed through principles of environmental justice and promoting social equity.

5. Conclusion

In this article we systematically reviewed 77 papers addressing adaptations to climate change by indigenous and local people in Mesoamerica, and the importance of Local Traditional Knowledge (LTK) for these adaptations. First, most publications do not explicitly define the type of knowledge used in climate change adaptations, but simultaneously fail to acknowledge the situated, heterogeneous, culturally embedded nature of local/traditional/indigenous knowledges (although their dynamic nature is sometimes recognized). Second, rainfall variability, droughts, and weather unpredictability are the most frequently expressed experiences of climate change. Third, the main adaptations implemented by smallholders are changes in the agricultural calendar and crops cultivated, a shift to more sustainable agriculture, and labor diversification to generate off-farm income. Our systematic review indicates that climate change is already putting significant pressure on smallholder agriculture across Mesoamerica and suggests that this pressure is exceeding the capacity for local, incremental adaptation. Subsequently, livelihoods, local community resilience, cultural identity, biodiversity conservation, and efforts for sustainable development are threatened. Fourth, we plead for immediate and real focus on LTK across Mesoamerican countries, in ways that deepen relationships and respect different culture and belief systems so that we can support local peoples against the climate crisis (Whyte, 2019). The region remains poorly researched compared to other locations given the complexity of the ethnic and linguistic cultural mosaic, yet the urgency to adapt to rapid environmental change is already apparent.

We agree with the growing literature identified in this systematic review on the need to support traditional knowledge and adaptation in rural communities in the face of accelerated climate change through integration of external resources. However, we call for care in how this support is provided. We recommend more research on climate change adaptation and traditional knowledge in Mesoamerica, especially in the Central American countries, with greater representation of local scientists and with co-production of knowledge, processes, and practices between researchers and indigenous and mestizo people. In addition, scientists and knowledge holders need to better communicate research results to local communities members and individuals involved in extension program design, development initiatives, and conservation. We also suggest that partnerships between external agricultural extension agencies and smallholders recognize the multiple values of traditional knowledge, looking beyond the potential for instrumental adaptations to the potential for ontological plurality and cultural and ecological integrity. Western technologies and consumption practices have largely caused climate change impacts for local communities in Mesoamerica and elsewhere. Western technologies may play a role in facilitating sustainable futures for local communities, but we now need to respect non-Western worldviews and knowledges and work together to develop adaptations to climate change and other complex social and environmental challenges.

Acknowledgements

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Appendix. List of papers reviewed

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