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REVIEW ARTICLE

Adapting nomadic pastoralism to climate change

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Abstract
This paper presents the results of a detailed review of the research literature on how nomadic pastoralists are being affected by climate change, how they are adapting, and challenges with using traditional knowledge in adaptation. It focuses on research that investigates local, and particularly traditional, knowledge of water, pasture, their variability, and livestock. This knowledge underpins nomadic livelihoods, so is a foundation for effective adaptation. Changes in the total amount of precipitation, and particularly shifts in its timing, and increases in the frequency and intensity of extreme events, are having the greatest impacts on herding livelihoods. Herders in drylands worldwide face common adaptation challenges: declining traditional water sources and pasture degradation. Herders' adaptation strategies fall into five major categories: movement to areas with better water and pasture, improving seasonal access to water, improving seasonal access to feed, shifts in herd composition, and livelihood diversification. Movement is central to nomads' adaptation, yet, as climate change takes hold, restrictions on movement are increasing for both socio-economic reasons and climate reasons. Many papers emphasised the importance of combining traditional knowledge and current science to guide adaptation decision-making at household, locality, and national levels. There is widespread concern about the decline in traditional knowledge. All the papers reviewed emphasised the need to support passing on traditional know-how. Herder women's know-how, in particular, is marginalised in the research literature, so their traditional knowledge should be a focus in further research. Herders' adaptations are mostly localised, incremental, and have a relatively short-term focus. As nomadic pastoralism moves further outside the range of historical experience, the possibility of more profound transformations looms.

Keywords Nomadic herding · Dryland agriculture · Climate change adaptation · Traditional knowledge

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1 Introduction

Accelerating climate change combined with changes in the global economy is threatening the existence of nomadic pastoralism—a highly adaptive and resilient way of life that has been practiced for millennia. Despite the declines that have already occurred, pastoralism is still the main livelihood for more than two hundred million people in mostly dryland regions around the world. These pastures support a substantial proportion of the world's livestock (Safriel et al. 2005, p. 640). Climate change and other human-induced factors, such as unsustainable land and water use, extractive industries, and urbanisation, are leading to further resource degradation in the main pastureland regions. In particular, the impacts of climate change on the temperate grasslands of arid regions are increasing very rapidly (IPCC 2021, 2022; MEA 2005).

The intentional and regular movement of herds and people to pastures is the defining characteristic of nomadic pastoralism, and a key feature of its adaptiveness. There are about 30–40 million nomadic pastoralists in the world, most of whom live in Central and East Asia, the Sahel region of North and West Africa, and other parts of Africa such as Nigeria and Somalia (Blench 2001). Nomadic livelihoods have been recognised as a sustainable way to utilise marginal pasturelands (IUCN 2012). However, nomadic communities and livelihoods are facing many challenges, most of which are related to social and economic shifts. As a result of government efforts to settle nomads through sedentarisation programs and implement land reforms, as well as the ongoing effects of dispossession associated with colonialism, nomadic populations are continuing to decrease (Koocheki and Gliessman 2005). The Kenyan government has implemented a program of land reform on the pastures of the Maasai tribes, as a result of which half of the pastureland is now in the hands of non-Maasai (Galaty 2013), for example. The pastureland of the Raika camel nomads in Rajasthan, India, has decreased dramatically since the mid-twentieth century (Köhler-Rollefson 1992). In Inner Mongolia, China, the open grasslands have been converted to irrigated agriculture (Brogaard and Xueyong 2002). In Iran, the expansion of the industrial and mining sectors and climate change have reduced the number of nomads dramatically (Annamoradnejad and Lotfi 2010). In addition, many nomadic communities are threatened by regional and civil conflicts and wars in the Middle East and Southeast Asia; for example, nomads have been living in danger in Afghanistan for several decades (Schütte 2012). More and more nomadic people are becoming semi-nomadic and sedentary ranch owners, or simply being excluded from their traditional lands.

Nomadic people's knowledge and practices embody learnings from deliberate movements across landscapes over millennia. They continue to adapt, and their evolving understandings are central to their ongoing adaptation to environmental changes. The integration of traditional knowledge and scientific knowledge, to guide adaptation in a world that has moved and is moving well outside historical experience, continues to prove challenging. Effective adaptation now requires co-production of knowledge with the robust engagement of scientists and local communities (Klenk et al. 2017). Since the adoption of the UNESCO (2001) Universal Declaration on Cultural Diversity, research on traditional knowledge of climate change has increased, but the literature on climate change adaptation is limited generally to perceptions of environmental change and practices related to local livelihoods and traditional knowledge (Klenk et al. 2017). In 2017, the UN launched the "Local Communities and Indigenous Peoples Platform" (UNFCCC 2017), aiming to give indigenous peoples and local communities an active role in shaping climate action by diversifying the knowledge system and promoting knowledge integration. There remain substantial barriers to integrating knowledges related to

Table 1 Overview of the literature search

Sampling strategy	Selective: studies relevant to climate change adaptation in nomadic pastoralism
Specific criteria	Engaged with and informed by pastoralists/herders
Approaches	Electronic subject searching only
Range of years	Fully reported
Limits	Peer-reviewed journal papers (& not grey literature) in English
Electronic sources	Web of Science Core Collection, Scopus, and CAB direct

the lower power of local and indigenous people in decision-making, however (Shawoo and Thornton 2019).

Pastureland livestock have enabled and may continue to enable sustainable production of valuable goods on marginal lands, and of course nomadic livelihoods are central to the well-being of nomadic pastoralists. So, climate change adaptation in these landscapes and pivotally the integration of local and scientific knowledges are important current research areas. This paper explores what the peer reviewed literature reports regarding the following questions:

1) How are nomadic pastoralists being affected by climate change?
2) How are nomadic pastoralists adapting to climate change?
3) How well placed are we to use nomadic pastoralists' traditional knowledge in adaptation planning?

2 Methods

This article is based on a systematic review of the research literature identified using key terms related to nomadic pastoralism. Table 1 describes the search criteria and their limits. The search logic used to identify papers for closer examination was as follows:

TOPIC: local knowledge OR indigenous knowledge OR traditional knowledge
AND TOPIC: climate change OR global warming OR climate variability
AND TOPIC: nomadic herders OR nomadic pastoralists.

After title, abstract, and key word screening, 340 articles were considered for initial review. To identify a final set of papers for analysis, we then identified those papers which explicitly considered the use of local knowledge in adaptation (understanding "local knowledge" as local people's knowledge, which now commonly blends traditional knowledge and scientific knowledge, e.g. from weather forecasting, in some measure). Many of those identified in the initial data set failed to explicitly consider the contributions of local knowledge. Using these criteria, 46 of the 340 publications were identified for in-depth analysis. We then individually reviewed the methods sections of all the excluded publications to check whether any of these papers actually investigated nomadic pastoralists' local knowledge, paying particular attention to whether review papers covered local knowledge. Through this process, we identified four more publications that warranted inclusion, giving

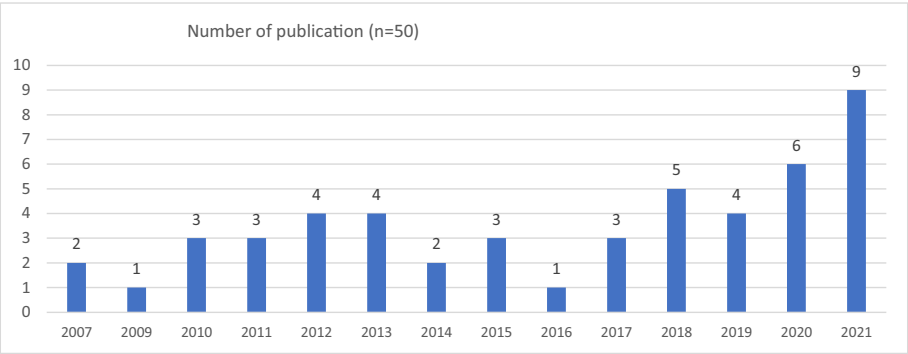

Fig. 1 Number of publications by the published each year

Table 2 Methods commonly used in the selected papers

Methods	Number of articles
Open and semi-structured interviews with pastoralists	29
Focus group discussions	15
A household survey	8
Key informants' interviews	6

us a total of 50 papers to examine closely for this review. Each of these four was a review article with focus much wider than nomadic pastoralism that nonetheless included useful discussions of pastureland areas, climate change, local knowledge, and local adaptation (Klenk et al. 2017; Naess 2013; Shawoo and Thornton 2019; Smith and Sharp 2012). The 50 publications identified are provided in Table A1 in an annex.

The papers included in this review were published in 2007–2021 (Fig. 1); the most prominent journals were "Climate and Development", "Journal of Arid Environments", and "WIREs Climate Change". Twenty-five papers were about nomadic pastoralism in Africa, 12 were from arid countries in Asia, and 9 described the experiences of nomadic pastoralists' adaptation to climate change in other regions and continents.

Most research projects used multiple methods. Interviews and focus group discussions with nomadic pastoralists were the most used methods for primary data collection (Table 2). A few used landscape walks, participatory fieldwork, and participant and field observations (Gantuya et al. 2021; Marin 2010; Zampaligré et al. 2014). Participatory rural appraisal and resource/participatory mapping were used in two papers (Iticha and Husen 2019; Zampaligré et al. 2014). In most papers, when used, key informant interviews played a supplementary role. Descriptive statistics were generally used to analyse the field data; meteorological data, which were often compared with herders' observations, were obtained from government sources.

To identify key themes, insights, and narratives from the selected literature, we have followed the general inductive approach to qualitative data analysis (Thomas 2006). NVivo 12 software was used for the initial coding (the node tree of the initial coding is in Annex 2), and a six-step process was used to identify the main themes and for the final thematic analysis (Table 3).

Table 3 Processes of data analysis (adopted from Braun and Clarke (2006))

Familiarising with data	Two steps of reading: - Reading 340 papers title, abstracts, and key words - Reading the selected 50 papers full texts
Generating initial codes	Used NVivo 12 software to generate initial codes in the selected papers
Searching for themes	Created thematic map using the NVivo produced coding list and references
Reviewing themes	Examined the thematic map and references: read all the collected extracts on each topic, checking to see if it lines up in a coherent pattern
Defining and naming themes	Identified three main themes (that reflect the research questions)
Producing the report	Writing results and discussion section structured as themes

3 Results and discussion

3.1 Nomadic pastoralists' experience of climate change

Nomads' knowledge of climate change is acquired through extensive observation of local environments and continuous herding practices that bring them into close contact with landscape. Pastoral ecosystems exposure to climate change, which has flow on effects for nomadic livelihoods, falls naturally into two groups: incremental, slow-onset changes, in precipitation in particular, and changes in the frequency and character of extreme events. This section surveys these changes (Annex 3 provides detailed lists).

3.1.1 Changes in precipitation and temperature, and their impacts

Using traditional forecasting methods, pastoralists have forecast and observed changes in rainfall variability in many places. In Africa, pastoralists report changes in precipitation in each of Ghana (Napogbong et al. 2021), Burkina Faso (Zampaligré et al. 2014), Eastern Sudan (Sulieman and Ahmed 2013), Ethiopia (Iticha and Husen 2019; Schmidt and Pearson 2016), Uganda (Nkuba et al. 2019), Kenya (Gachathi and Eriksen 2011), and Tanzania (Kihila 2018). In Asia, pastoralists from Eastern (Tugjamba et al. 2021b) and Southern (Marin 2010) regions of Mongolia, Iran (Ghazali et al. 2021), Pakistan (Ahmad and Afzal 2021), and China (Fu et al. 2012) have also observed changes in precipitation.

In all regions, the variations pastoralists have experienced in the *timing* of precipitation have been more important for their livelihoods than the variations they have experienced in the *total precipitation* (Saboohi et al. 2019; Tugjamba et al. 2021b). From the changes in precipitation and temperature follow a reduction in the overall quality of pasturelands (Iticha and Husen 2019; Tilahun et al. 2017; Tugjamba et al. 2021b). At the same time, socio-economic shifts, notably increasing demands for food and natural resources, e.g. minerals, are driving further changes in land use in the drylands occupied by nomadic pastoralists (Nkuba et al. 2019). These combined climatic and socio-economic influences reduce the mobility of nomads—both how often they move and where they are able to move to (Schmidt and Pearson 2016; Tugjamba et al. 2021a).

In Africa, Fulani herders of Ghana have observed that the dry season is becoming longer, and there are fewer rainy days. The longer dry season, increased frequency and length of dry spells, shrinking sizes of water bodies, and the related stunted growth and

reduced diversity and abundance of grass species have become major threats for Northwest Ghanaian nomads (Napogbong et al. 2021).

The Afar pastoralists of Ethiopia report changes in precipitation and temperature over the last few decades (Tilahun et al. 2017) and that this has led to changes in all landscapes (Schmidt and Pearson 2016). The rainy seasons have changed; *Karma* (June to September) and *Sugum* (March to April) are shorter and *Dadda* (December) has disappeared. The combined effects of the reduction in rainfall and changes in temperature in Ethiopia have led to a dramatic reduction in the quantity and reliability of traditional water sources for livestock and human needs, resulting in some distress migration in search of alternative livelihoods (Schmidt and Pearson 2016). Similarly, in Eastern Sudan, pastoralists have witnessed that rains are failing, and the rainy season is short (Sulieman and Ahmed 2013). Pastoralists in Burkina Faso identified the major effects of climate change on livestock husbandry systems as the shrinkage of grazing areas and the decline of forage resources, leading to lower animal productivity (offspring numbers, milk, and meat yields) (Zampaligré et al. 2014). The main climate change-induced problems in Tanzania also include water scarcity and a lack of pasture (Kihila 2018). Pastoral communities of the semi-arid regions of Uganda have also experienced similar climate change effects on water availability and pasture resources (Egeru et al. 2015).

Asian pastoralists are facing similar problems to those of African nomads. Herders from Northeast Mongolia observed that weather and environmental conditions had changed significantly over at least the past three decades and have seen changes in precipitation and the seasons and suggest a seasonal shift has occurred as spring is a continuation of winter and summer is getting shorter (Tugjamba et al. 2021b). The herders from other regions of the country also report that the plant-growing season has changed due to less or late rainfall (Gantuya et al. 2021; Marin 2010). While the change to total precipitation has been modest, changes to the timing of precipitation have been shortening the period of summer plant growth, and this necessitates significant changes to herding practices (Gantuya et al. 2021; Tugjamba et al. 2021b). Reduced biomass is reducing the productivity of livestock, with cattle and sheep becoming smaller, and the milk yield from cows decreasing year by year (Tugjamba et al. 2021b).

Qashqai and Kashkooli nomads of Iran report that climate change has severely affected summer pasturelands. Wind speed and temperature have increased; precipitation has decreased (Ghazali et al. 2021). Changes in the location and timing of precipitation, including shifts from snowfall to rainfall, have been observed, and relatedly water outflow rates from springs have decreased, with some drying up (Saboohi et al. 2019). These changes greatly reduce rangeland quality and increase food security risks among Iranian nomads (Ghazali et al. 2021). Kyrgyz nomadic communities in Afghanistan report that they experience spring as now a continuation of winter due to a delay in the usual rains that accompany spring. Furthermore, fodder in summer pastures is being burnt more often—in wildfires and through being gathered by cropland farmers communities for fuel—and animals are not gaining the necessary weight to sustain them through the winter (Kassam 2009).

Climate change has adversely affected pastoral communities in Pakistan with increased exposure to floods and droughts and increases in livestock diseases, particularly as the average condition of animals is declining due to increasing difficulties accessing feed and water. Nomadic Pakistanis are seeing declines in livestock health and productivity and increased stock losses due to the lack of adequate water and pasture (Ahmad and Afzal 2021). In the Pamir Mountains in the historical Badakhshan region, now divided between Afghanistan and Tajikistan, changes in precipitation are also reported, and traditional

grazing lands have become less productive. These changes forced pastoralists to seek grazing at higher elevations, severely affecting livelihoods in the region (Kassam 2009).

In the province of Tibet (southwest central China), pastoralists report similar variations that the climate has "worsened" since the early 1990s and a delay in the onset of rainfall and shortening of the "summer" period has been also observed (Fu et al. 2012). They particularly noted changes in the timing and length of the growing seasons, specifically highlighting that summer is starting later, summers are shorter, and that the greening of plants is delayed. Since the early 1990s, people are also contending with delayed rainfall and shortening of the summer season contributing to decreased grassland productivity and thus decreased livestock productivity, as indicated by declining milk yields in the Tibetan plateau (Fu et al. 2012). Tibetan nomads report that snowlines are receding and moving upslope, clear evidence of the warming of the Tibetan plateau (Klein et al. 2014).

In the other parts of the globe, Quelcayinos, Indigenous Andean Pastoralists in Peru, have observed diverse climate-related shifts in the water cycle including shifts in the seasonality, quantity, and intensity of precipitation (Postigo 2021). Quelcayinos noticed alterations in the vegetation and linked it to water changes, particularly in the *bofedales* (high-altitude wetlands or peatlands) that supply crucial fodder for alpaca. They observed that the *bofedales* changed in three ways: shrinking, breaking up into little patches, and drying out. The majority of Quelcayinos attributed the loss of *bofedales* to the combined effects of decreasing water availability and increasing heat intensity (Postigo 2021). The Sami, reindeer herders in Sweden, felt the weather and the seasons have changed and that this is causing the shrinkage of grassland leading to the changes of the herding practices (Furberg et al. 2011).

3.1.2 Extreme events

Nomadic pastoralists commonly emphasise the increasing frequency of extreme events and increases in their intensity. Drought is mentioned often; droughts are occurring more often in all dryland pastures, and are a major stress on nomadic livelihoods. In Kenya's drylands, for example, more frequent, longer, and more severe droughts are affecting the quality and quantity of water resources—dams and wells are drying up—leading to livestock deaths, reduced incomes and increased poverty, and loss of life (Gachathi and Eriksen 2011). The Afar pastoralists of Ethiopia report that the frequency of droughts is increasing, estimating that they now occur every 1–2 years compared to around once every 8 years (Iticha and Husen 2019). For both, the Afar and Borana pastoralists of Ethiopia, the worst socio-economic effects of climate change stem from lack of water (Schmidt 2006); feed shortages are causing die-offs of great numbers of livestock (Tilahun et al. 2017). In the Rwenzori region of Western Uganda, by contrast, pastoralists are facing problems with floods, which limit nomadic movement of livestock, reducing access to pastures. Floods are also the quality of, and access to, safe water for livestock and humans (Nkuba et al. 2019). In Eastern Sudan, pastoralists depend mainly on artificially excavated holes known locally as *hafirs*, rather than underground wells which are very rare in the area (El Hadary and Samat 2012), a particularly precarious set of circumstances.

In the northern hemisphere, nomads are facing droughts and more severe winters. In Kazakhstan, herders advised that these climate extremes severely impacted their livestock businesses and that colder winters were limiting their activities. Drought reducing pasture biomass in the growing season is a critical factor for pastoralists in the Kazakh Altai. Drought has also resulted in a shortage of drinking water for livestock (Hauck et al.

2016). In Mongolia, the most common weather-related problems identified by herders are water scarcity, drought, white *dzud*[1] (almost impenetrable snow cover impeding livestock's access to underlying edible plants), dust/sand storms (Marin 2010), and black *dzud* (a lack of snow in the pastureland which leads to livestock suffering from a lack of water). Black *dzud* occurs following a dry summer and has been happening every 2 to 3 years in the last two decades (Tugjamba et al. 2021b). Increasing temperature, changing patterns of precipitation, and increasing frequency of droughts and black *dzud* have led to a reduction in water in the open steppe pastures (Tugjamba et al. 2021a).

These climate change effects are combining with, and in part leading to, socio-economic changes that are making nomadic livelihoods more marginal. The transition away from common property regimes accompanying modernisation processes is transforming the lives and livelihoods of Afar pastoralists in Ethiopia (Schmidt and Pearson 2016). The Samburu in Kenya and the Fakara in Niger are clear examples of pastoral systems in Africa where the combined effects of demographic, economic, socio-political, and climatic pressures are driving many nomadic pastoralists into non-livestock-based livelihood strategies (Ayantunde et al. 2011). Exposure to aspects of climate change is also contributing to more social tensions and conflicts in some regions, and in many cases is exacerbating pre-existing tensions and resource disputes. For example, in Kenya, pastoralists migrating to new areas where pasture and water are available are coming into conflict with other pastoralist clans from the same ethnic group, and harmful confrontations have occurred (Gachathi and Eriksen 2011). Conflict between communities about resource access and use has also increased in Burkina Faso (Zampaligré et al. 2014).

The literature demonstrates that the observations of nomadic pastoralists overwhelmingly align with meteorological observations (Marin 2010; Zampaligré et al. 2014; Tilahun et al. 2017). Pastoralists' observations provide a fine-grained, detailed understanding of changes that increases understanding of what is occurring and is helpful for herder decision-making. Traditional forecasting methods, which are integrated with pastoralists' ways of observing change, are often important in this decision-making. However, another effect of climate change is that the reliability of these traditional forecasting methods is decreasing, as climate change and interdependent socio-ecological shifts take pastoral communities outside the range of historical experience (Ifejika et al. 2010; Iticha and Husen 2019). Some of the complications are side effects of efforts to increase water availability. For example, in Mongolia, cloud seeding has made rainfall more unpredictable from the perspective of traditional weather forecasting (Tugjamba et al. 2021b).

Taken together, these findings make it very clear that climate change is affecting nomadic pastoralists in all regions through clear and consistent changes in the amounts and patterns of precipitation and that these are having largely negative consequences for water availability, pasture diversity and biomass, and pastoral livelihoods. They face common adaptation challenges: all face water resource problems and pasture degradation.

3.2 Nomadic pastoralists' adaptation approaches

Nomadic pastoralists' adaptation practices have emerged from in-depth individual and collective observation of the landscape while herding their livestock, and are evolving in response to climate and other socio-ecological changes. Their adaptation strategies fall into

[1] A *dzud* is a Mongolian term for a severe winter in which large numbers of livestock die.

four major categories: changing movement patterns to better fit the availability of water and feed; modifying herd composition; use of planting, feed storage, and water storage to reduce risk; and livelihood diversification.

3.2.1 Changing movement patterns to better fit the availability of water and feed

Traditional nomadic movement has a central role in ensuring the sustainability of nomadic pastoral communities (Humphrey et al. 1999). It is the core strategy for managing familiar variability in water and pasture, and for responding to disasters and other shocks (Fernandez-Gimenez and Le Febre 2006; Naess 2013; Blanco and Carrière 2016; Tilahun et al. 2017; Napogbong et al. 2021). Mobility is demonstrably a highly efficient strategy for coping with scarcity of resources in drylands of African Sahel, for example (El Hadary and Samat 2012). Mobility is also a means of husbanding resources, particularly pasture: the Afar migrate to allow rest periods for vegetation regeneration and to provide animals with a variety of fodder types (Schmidt and Pearson 2016), and traditional nomadic movement and herding practices are used to limit the use of pastures, e.g. preventing off-season grazing (Tugjamba et al. 2021a).

Nomadic movement is enabling ongoing adaptation to the effects of climate change. Qashqai pastoralists in Iran, for example, have been changing migration routes and locations at which they pause to cope with these adverse effects (Saboohi et al. 2019). Moving livestock at the onset of drought (e.g. Reed et al. 2007) and migrating to humid zones (e.g. Zampaligré et al. 2014) are familiar practices. Using isolated areas routinely and staying for shorter periods at each campsite are the most common practices for responding to the droughts among the pastoralists (Kihila 2018; Schmidt and Pearson 2016). Because nomadic movement is the centre of a culturally revered way of life around which pastoral communities have been organised for many generations, movement continues to have a central role in nomadic pastoralists' climate change adaptation (Nkuba et al. 2019; Postigo 2021; Zampaligré et al. 2014).

3.2.2 Modifying herd composition

Modifying herd composition in response to changes is occurring in many communities. Mongolian herders are modifying the composition of herds and investing in new breeds (Tugjamba et al. 2021a). In Burkina Faso, pastoralists are shifting from cattle to goats and sheep (Zampaligré et al. 2014), and yaks have begun to be substituted for sheep and goats in the Tibetan plateau (Fu et al. 2012). The Afar pastoralists of Ethiopia strategically mix their herds, which include camels, cattle, goats, and sheep, to utilise various types of pasture and to reduce risk: diversity hedges against the risk that extreme conditions will kill most animals of one species (Schmidt and Pearson 2016). These shifts in herd composition can be differentiated into two main groups: (i) shifts in the ratio of species in a herd (e.g. decreasing the proportion of sheep and increasing the proportion of goats, as is happening in Mongolia (Tugjamba et al. 2021a), which involves a relatively low learning curve and lower investment; and (ii) changing the species herded (e.g. moving from cattle (vulnerable to warming) to sheep and goats (both heat tolerant and, on an individual basis, requiring less water and feed than cattle), as is happening in Burkina Faso (Zampaligré et al. 2014), which involves a relatively high learning curve and other costs. These shifts in practice are partly about climate, but they are also adaptations to shifts in market access (e.g. (Tugjamba et al. 2021a)). In Mongolia, one response to improved access to markets has been to

increase herd sizes to increase revenue, and this is one of the factors driving land degradation (Tugjamba et al 2021a).

3.2.3 Use of planting, feed storage, and water storage to reduce risk

To manage the mitigation effects of increased pasture variability, planting to provide additional feed is occurring in some locations (Napogbong et al. 2021; Tugjamba et al. 2021a), and feed is being stored to help animals survive through harsh winters and droughts (Tugjamba et al. 2021a). Building small dams and other storages is an important strategy for managing increasing variability in access to water (Ghazali et al. 2021; Saboohi et al. 2019). In some locations, new wells are being dug to offset increased unreliability of surface water sources (e.g. Tugjamba et al. 2021b). In Tanzania, Nomadic pastoralists use strategies such as rainwater harvesting in ditches (*malambo*—construction of very small, commonly temporary local water reservoirs) and check dams (Kihila 2018). In addition, to protect livestock and people from extreme weather, shelters are being built (Napogbong et al. 2021; Saboohi et al. 2019; Tugjamba et al. 2021a).

3.2.4 Livelihood diversification

Diversifying sources of income, to reduce reliance on income streams from herd animals, is widespread. In Kenya, many pastoral households now collect and sell plant gums and resins (Gachathi and Eriksen 2011), for example. In some countries, such as Mongolia (Tugjamba et al. 2021a), Kyrgyzstan (Sturød et al. 2020), and Iran (Shekari et al. 2022), tourism activities are an important way of diversifying income. Non-pastureland employment is also important. In Burkina Faso, seasonal migration of youths to cities where they find temporary jobs contributes (Zampaligré et al. 2014). In Mongolian herder household, women may find employment in village centres, which aligns well with providing modern schooling for children (Tugjamba et al. 2021b).

3.2.5 Problems with restricting or ending movement

Building storage infrastructure (used seasonally) to buffer against increasing unreliability of water (e.g. dams, wells) and pasture (e.g. hay stores) and extreme weather (e.g. barns), planting to provide additional feed, and livelihood diversification that demands a closer connection with local centres all tend to reduce herders' mobility. Non-environmental factors are also reducing the spatial range and temporal length of movements; for example, some young herders are choosing to live closer to mobile telecommunications networks and to schools for school-age children (Tugjamba et al. 2021a).

All the above are herder-initiated restrictions on movement. However, the most radical changes in movement patterns have been driven by top-down processes—governments supporting other land uses such as mining, and settled agriculture. In Burkina Faso, for example, some nomadic communities are shifting to sedentary lifestyles or informal settled livelihoods due to the unfavourable government policy and other factors (Zampaligré et al. 2014). These actions are leading to maladaptations such as increasing density of herding and over exploitation of groundwater reserves. Mobility restrictions are increasing due to land privatisation and fragmentation in East Africa and due to expansion of crop field into grazing land in West Africa (Ayantunde et al. 2011). Restrictions on mobility are also increasing in Botswana (Reed et al. 2007). Land tenure changes in favour of mining,

infrastructure, and settled farming are playing a major role in many regions (Næss 2013). In many places, nomadic livelihoods are viewed negatively (Næss 2013). The contrast between Mongolia, where the government has allowed pastoralists to continue their traditional group ownership institutions, which rely on large-scale movements between seasonal pastures, and Inner Mongolia in China and in a number of neighbouring countries which have introduced state agricultural collectives involving permanent settlements, is instructive: there is markedly less environmental degradation of pastureland in Mongolia (Ostrom et al. 1999).

Where nomadic pastoralism is still supported, but movement is substantially more restricted, the potential for sustainable nomadic herding is reduced. Movement is at the core of nomads' management of the challenges of environmental variability, and climate change is increasing that variability, at the same time as socio-political and climate influences (e.g. desertification) are reducing capacity to move. There is a fundamental tension here (Næss 2013).

3.2.6 Long-term adaptation?

Adaptation strategies are blended as a matter of course to cope with local circumstances. In Eastern Sudan, for instance, pastoralists use herd mobility, flexible stocking densities, and diversification in animal species, as well as diversification of income generating activities (El Hadary and Samat 2012). In northern Mongolia, shifts in herd composition, diversification of income sources, and creating small dams and wells all play a role (Tugjamba et al. 2021a). With the intensification of climate change, nomadic pastoralists' mobility strategies continue to have a central role, and they are being combined with many other kinds of adaptation (Nkuba et al. 2019; Sulieman and Ahmed 2013; Tugjamba et al. 2021a). This flexibility underlines the innovativeness and adaptive capacity of herding communities.

However, most of the adaptation strategies and actions undertaken by nomadic pastoralists who are continuing with pastoralism aspire, in Pelling (2010) terms, to resilience (stability) or transition (incremental change), but not to transformation (radical change). At the household level, herding families that leave nomadic pastoralism are making transformative changes. At the community level, however, kinds of transformation that might sustain herding as a livelihood have not been identified. The focus is on adapting incrementally with a view to short- and medium-term viability (Kihila 2018; Tugjamba et al. 2021a; IPCC 2022). Whether the shifts in herding practice that are occurring will prove to be adaptive in the long term remains to be seen. The latest IPCC (2022) report warns that aridity will be more intense in drylands globally. Current and evolving water management practices may not be effective in coping with the adverse effects of droughts at 1.5 °C global warming by 2041–2100 (Davies et al. 2016). Problems with access to water in drylands will increase (IPCC 2022). At the least, new strategies are likely to be needed to ensure continued adaptation to water vulnerability (Postigo 2021). However, it may be that many areas of pastureland currently occupied by nomadic peoples will be unusable, or have greatly reduced carrying capacities for livestock, by 2100 (IPCC 2022). The cost of providing water to preserve nomadic livelihoods may exceed herding communities' and governments' willingness to pay. On the climate trajectory we are on, radical transformation for many more herding communities may well lie ahead.

It is clear from the analysis above that nomadic pastoralists are demonstrating innovation and in many cases continuing to adapt effectively to the circumstances that they are confronting. The bottom-up nature of many of the innovations underlines the importance

of having adaptation approaches that make sense to local people if they are to be enacted. We turn therefore to a review of how traditional knowledge is being used in adaptation planning.

3.3 Traditional knowledge in adaptation

3.3.1 The importance of traditional knowledge

Traditional knowledge has a central role in nomadic pastoralists' adaptation to climate change, as it is what carries knowledge of water sources, pasture, their variability, and implications of these for movement and sustainable use generally. Nomadic communities around the world have extensive knowledge of plant development, livestock species' foraging needs plays, and the implications of local seasonal shifts for plants and livestock. They use this knowledge to make efficient use of grazing resources by livestock (Singh et al. 2020). It is widely recognised that pastoralists have a reliable and widespread understanding of landscape and pasture change (Gantuya et al. 2021), which can help reduce uncertainty and support adaptation to climate change (Marin 2010).

Speaking of "traditional knowledge" here points to ways of understanding that developed long before nomadic communities' encounters with modern science and technology. For herders, traditional ways of understanding the landscape, climate, and herding are the foundation of their forms of life. Modern scientific and technological know-how can extend, complement, and support tradition, bringing different perspectives, and potentially making distinctive contributions as pasturelands move outside the range of historical climatic and socio-economic experience. As implied above, "local knowledge"—the understanding that nomadic pastoralists are using as they practice their livelihoods—is a crossing of traditional ways of understanding with herders' understandings of modern science and technology. In all communities, nomadic people's know-how continues to evolve as climate and culture co-evolve (Reed et al. 2007).

There is clear evidence that nomadic pastoralists in drylands have valuable local knowledge of climate change, which is gained in part through traditional practices of pasture use, movement, and observation (Zampaligré et al. 2014; Tilahun et al. 2017; Tugjamba et al. 2021a). Tilahun et al. (2017, p. 2) remark, for example, that "observations by Afar pastoralists on temperature and precipitation trends over the past four decades were largely consistent with existing empirical data based on meteorology". This knowledge generally complements meteorological insights, by bringing more spatially fine-grained understanding of shifts, and by bringing focused insight into how shifts in weather and climate affect pastoral livelihoods. Pastoralists' know-how can function as an early warning system, improving resilience to droughts, for instance (Tilahun et al. 2017).

As pastoral landscapes move outside the range of historical experience, communities can be expected to encounter unexpected limitations to traditional know-how (Ifejika et al. 2010). Scientific knowledge takes on greater practical importance. Equally, though, when it comes to shaping practical action in nomadic pasturelands, the fine-grained appreciation of local variability and livelihood relevance remains essential (Kihila 2018). So, effective adaptation needs to bring both knowledges together.

The rapid changes in the environmental, social, and economic spheres have led policy makers in many countries to not value traditional adaptation practices highly. All the papers reviewed imply that this is a flawed approach. All recommend improving the use of local knowledge in adaptation policies and strategies. A corollary that is very concerning is

that the loss of traditional knowledge reduces opportunities for future adaptation (Fernández-Giménez and Fillat Estaque 2012).

Despite the consensus about the importance of better integration of nomadic pastoralists' traditional knowledge and western scientific knowledge, there is not much discussion of how to integrate them, beyond thoughtful recommendations about fostering dialogue and movements toward consensus (e.g. Iticha and Husen 2019). The question of the commensurability of nomadic pastoralists' knowledge systems and western scientific knowledge is not engaged with closely in the literature analysed here. In general, implicitly, forecasts and recommendations from the two knowledges are approached additively, with differences exposed for examination. It is an empirical question whether direct efforts to find ways to make the knowledge systems commensurable (e.g. by translating them into each other's frameworks and adapting each knowledge system in response) would be helpful in shaping nomadic pastoralists adaptation to climate change. This is not a question with which the literature engages substantively. It may well be simpler to simply focus on brokering more thorough explorations of the practical consequences arrived at by users of each knowledge system (e.g. Reed et al. 2007; Iticha and Husen 2019; Lavrillier and Gabyshev 2021).

3.3.2 Adapting herding practice

The shifts in herd composition in response to shifts in climate, mentioned above, is an illustration of how traditional knowledge can helpfully inform adaptation decisions at the household level (El Hadary and Samat 2012; Tugjamba et al. 2021a). Experience with, and knowledge about, diverse kinds of livestock is a platform for adaptation, as it is in pastoral communities worldwide (Vermeulen et al. 2015).

Integration of scientific and traditional knowledge, to guide decisions about movement, is already commonplace at the household level in pastoralist communities. In Uganda, for instance, both scientific and traditional weather forecasting methods are used, especially for long-range forecasts; one of the effects has been that herders are moving more often (Nkuba et al. 2019). In Mongolia, herders use mobile phones to gain access to up-to-date information on commodity and livestock product prices, as well as meteorological information. Mobile phones are used for many purposes, including to share information on pasture condition, and to keep in touch with extended family. These uses of technology and science underline nomadic people's capacity to adapt (Marin 2008).

3.3.3 Adapting policy

Above the household level, effective use of traditional knowledge alongside knowledge of science and technology is rare. Policy makers at all levels find the integration of nomadic pastoralist knowledge and formal science challenging (Marin 2010; Reyes-García et al. 2016).

The main obstacles to the use of pastoralists' local knowledge to shape adaptation in policy and management are cultural and institutional. Pastoralism is often seen as a fading tradition, and as having little appeal to younger generations (Fernández-Giménez and Fillat Estaque 2012). A lack of appreciation of local knowledge's importance is commonplace in developing countries. Policy makers in the Andes, for example, are seen as having an inadequate understanding of the value of, and need for, integration of local and formal scientific knowledge systems (Postigo 2021). In some African countries, an ongoing negative

political discourse around pastoralism (Pedersen and Benjaminsen 2008) has played a major role in limiting the use of local knowledge to support adaptation to climate change. In Sudan, El Hadary and Samat (2012) suggest that herders' ability to make full use of their ecological knowledge is undercut by irrational development policies that have led to a sharp decline in pastoral mobility. The situation is similar in most Asian countries, with the exception of Mongolia; and beneficial effects from Mongolia's supportive policies are not particularly obvious on the ground (Tugjamba et al. 2021a).

Above the household level, the main use of local knowledge (and thence of the traditional knowledge embedded in it) is as a supplementary data source. As Shawoo and Thornton (2019) report, pastoralists' contributions are usually present simply as a distinctive kind of field observation. Local observations are an important complement to meteorological measurements, detailing local phenomena. They can also draw attention to phenomena missing from mainstream science-based reports and can help with formulation of new hypotheses and research questions (Byg and Salick 2009). However, this is a very limited use, from an adaptation perspective.

Nomads' knowledge is acknowledged and appreciated by some decision makers as a basis for developing viable adaptation strategies and policies, especially at the local level (Tilahun et al. 2017; Ghazali et al. 2021; Xuan et al. 2021). However, for the most part, integrating local knowledge into adaptation policies and strategies remains an aspirational goal that the literature calls for, rather than a lived reality.

3.3.4 Traditional knowledge at risk

Traditional knowledge has traditionally been passed on by within-family apprenticing: children and young adults learning from parents and other older extended family members. Traditionally household heads are the authorities. As a result, in most ethnographic studies into pastoralism, older men are the key informants about traditional knowledge (Furberg et al. 2011; Klein et al. 2014; Tilahun et al. 2017; Iticha and Husen 2019). This pattern hints at two major concerns regarding intergenerational flows of understanding. Firstly, as the land available for pastoral use contracts, and younger people take up other livelihoods, how is passing on of traditional knowledge being affected? Secondly, what is happening with women's knowledge?

There is widespread concern in the research community regarding loss of traditional knowledge (Ifejika et al. 2010; Blanco and Carrière 2016; Radeny et al. 2019). Disruption of knowledge transmission systems, insufficient documentation, and the influence of modern technology all put traditional knowledge at risk (Radeny et al. 2019). If younger generations lose or fail to acquire traditional knowledge of pastoralism, this reduces adaptive capacity (Berkes et al. 2000). All the papers reviewed highlighted the urgent need for institutional support to assist in strengthening the transmission of traditional knowledge. These calls reflect the fact that traditional institutions—nomadic households and their livelihoods—are changing quickly in all regions. Nomadic pastoralism globally is experiencing a weakening of traditional knowledge.

Implicitly it is the loss of men's knowledge that is foregrounded in these calls. Traditional gender roles, which are well differentiated in nomadic pastoral communities (cf. Klein et al. 2014), mean that much transmission is from males to males or from females to females.

The effects of socio-economic change on these gendered intergenerational flows of understanding vary by region. In Morocco, young men tend to go to school and then seek

paid work, so they spend much less time learning herding practices than was usual a few generations ago. Their local knowledge generally, and their traditional knowledge in particular, is much thinner. Conversely, young Moroccan women attend primary and sometimes secondary school, but then return to their family before marriage. They then participate in caring for livestock and other livelihood activities in an apprenticing environment (Blanco and Carrière 2016). By contrast, in Mongolia, herding households very often send their daughters to school to finish college, but dropout rates from formal education are high among herder family boys. In young Mongolian herder families, wives then often stay in the soum (village) centre to take care of children and send them to school, while husbands take care of livestock and live nomadically (Tugjamba et al. 2021a). So, in Mongolia, it is traditional knowledge passed on particularly by women about women's roles that is attenuating most quickly. Efforts to strengthen passing on of traditional knowledge obviously need to be shaped by local circumstances.

Twenty of the fifty papers that explore pastoralists' local knowledge collected data from both women and men in nomadic communities. However, when women's experience of climate change and their adaptations are considered, the focus is on their roles as herders, commonly as female household heads. Women in many locations have distinct roles, and these are rarely considered—and never in depth in the papers reviewed here. Ayantunde et al. (2011) comment that women "are in charge of gathering roots and vegetables, tending to children and collecting water". We noted above the contrast between women's roles in Morocco and Mongolia. However, women's contributions to herding households' livelihoods, apart from herding itself, are almost unexplored in the literature on climate change exposure and adaptation. In efforts to document traditional knowledge, to offset the decline of learning by apprenticing, the *distinctive* aspects of women's experience and knowledge that is passed on between females need to be a focus.

3.3.5 Ways further research can contribute

This survey of the research literature points to four ways in which future research could change, to help nomadic communities use traditional knowledge more effectively, in climate-change adaptation.

1. Little of the research surveyed had research partnerships—e.g. use of action research methods—at its core. In general, herders simply provided information used by researchers. Research partnerships—with co-production and co-learning—could clearly strengthen adaptation research and increase its impact. Both herders and national policy communities would be apt partners. Working with them together would be particularly apposite, as making better use of local knowledge in adaptation planning is a central challenge (Naess 2013; Kihila 2018; Postigo 2021; Xuan et al. 2021).
2. Research directed at strengthening the integration of traditional and scientific knowledges in adaptation decision-making could play close attention to how these knowledges are already being used together in herder household decision-making, as this is where integration is most advanced. Potentially the policy community which is focused at social and spatial resolutions above the household could learn from this experience.
3. Given the shift in emphasis from learning by doing while apprenticing to more text and multimedia-based storing and sharing of knowledge, there is a role for researchers producing research outputs that document traditional knowledge using new technologies that are accessible to herders.

4. It is clearly appropriate for the research community to pay closer attention to women's traditional knowledge, as currently dominant research methods are, *de facto*, marginalising women's distinctive experiences and their contributions to livelihoods generally, and to climate-change adaptation, in particular. Given the traditional gender roles in many nomadic communities, supporting women researchers would make an important contribution.

4 Conclusions and recommendations

Numerous scientific papers have been published on how nomadic pastoralism is being affected by climate change, most notably since 2000. Relatively few bring pastoralists' voices to the fore, however. Few explore how pastoralists are experiencing climate change, how they are adapting, and how their traditional knowledge—which underpins their livelihoods—is being used and underused in adaptation.

Changes in precipitation—reductions in the total amount and particularly shifts in timing—and increases in the frequency and intensity of extreme events are having the greatest influence on herding livelihoods. Herders' observations of these shifts align well with meteorological data, but provide local intricacy and an appreciation of how these shifts impact pastoral livelihoods which is particularly important for adaptation planning by both herding households and policy makers. Herders in drylands worldwide face common adaptation challenges: declining traditional water sources and pasture degradation.

These climate pressures are co-occurring with other shifts, notably governments favouring other land uses such as mining and settled agriculture, reducing the land available for nomadic livelihoods, and increases in educational and employment opportunities for young people. Policy support for nomadic herding is commonly weak. The integrated effects of these changes are leading—in many cases forcing—some households to abandon herding livelihoods.

Nomadic movement continues to underpin herding households' adaptation to environmental variability. Herders are also adapting by adjusting the mix of livestock species they herd, and by taking steps to store water and pasture. Many herding households are taking steps to diversify their income, including contributing to cultural tourism and having family members work in town centres or cities.

Most of these adaptation strategies are fit for purpose under relatively modest shifts in climate; there are grounds for concern about whether they will prove to be adaptive if shifts in climate over the century are relatively large. Nomadic herding has been a sustainable way of using relatively marginal land; herding is therefore very sensitive to inimical climate shifts.

Traditional knowledge—of water, pasture, their variability, and livestock—underpins nomadic herding. There is widespread concern about its decline, as passing this know-how from older to younger herders becomes more difficult. All the papers reviewed emphasised the need to support passing on traditional know-how. In the research literature, herder women's know-how, in particular, is, de facto, marginalised, so their traditional knowledge should be a focus in further research.

Socio-economic development and climate change, which is one of its major unintended consequences, are changing biosphere dynamics in ways that move the system outside the range of historical experience. Recognising that traditional knowledge has taken shape over periods of history where the rate of socio-economic development has been much slower in many locations, and climate change has been modest, and valuing both scientific and traditional knowledges, many papers emphasised the importance of combining traditional knowledge and current science to guide adaptation decision-making at household, locality,

and national levels. In general, households are currently doing this more effectively than policy makers. There is widespread potential for policy processes to improve by giving more heed to local knowledge.

Pastoralists' socio-economic vulnerability to climate change is shaped strongly by their marginalisation (Sulieman and Ahmed 2013). In many settings, there is a silent acceptance of the opportunities for nomadic livelihoods reducing. The limits of nomadic pastoralism's capacity to adapt are not known, and the likelihood that many of the alternative land uses on these marginal lands are unsustainable under climate change is high. Silent acceptance of this loss of opportunities for nomadic livelihoods is analogous to the grievous situation atoll countries face: in many quarters, the future loss of atolls as sea levels rise is now taken for granted and this undermines efforts to both mitigate and adapt (Barnett 2017). Silence and inaction foster maladaptation. An adaptive response must place herding communities' know-how at the centre, and embrace a thorough going use of both traditional and scientific knowledges to explore options as our journey outside the range of historical experience continues.

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Declarations

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