Food security among dryland pastoralists and agropastoralists: The climate, land-use change, and population dynamics nexus

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Abstract

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Keywords

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Introduction

Food security exists when sufficient, safe, and nutritious food is available to a target population at all times, so that basic dietary needs for a healthy and active life are met (FAO, 2006). Four main dimensions determine food security: (1) food availability; (2) economic and physical access to food; (3) food utilization, or nutritional status; and (4) stability of the previous three conditions. All these dimensions must be simultaneously fulfilled to achieve food security. Seasonal food security is usually predictable and follows a sequence of known events. Conversely, seasonal food insecurity reflects temporal fluctuations in climate cycles, cropping patterns, employment and income opportunities, and public health. Transitory food insecurity is relatively unpredictable and is temporary. Chronic food insecurity is long-term or persistent. The longer its duration and the higher its intensity, its outcomes are more severe, and may result in acute food and livelihood crises, humanitarian emergency, and catastrophic famine (FAO, 2008a). Related terms include undernourishment, food deprivation, hunger, and malnutrition, all of which describe different phases of inadequate nutrition levels (Hoddinott et al., 2012).

Drylands cover an estimated 41% of the world's earth surface, make up 44% of the world’s cultivated lands, and support 50% of its livestock (Davies et al., 2016). According to the Global Food Security Index (GFSI) – a dynamic quantitative and qualitative model made of 28 different components, which provides a tool for assessing food security for many countries around the world – the most vulnerable region is Sub-Saharan Africa. Other major regions lacking food security are the Middle East, North Africa, Central Asia, South Asia, South-East Asia, South America, and Central America (The Economist Intelligence Unit, 2017). Of these regions, extensive areas are considered drylands, including dry-sub-humid, semi-arid, arid, and hyper-arid lands (Dobie, 2001; Reid et al., 2014; Stringer et al., 2017).

Large parts of countries are considered developing, less developed, or least developed countries (LDCs), with moderate-to-low gross domestic product (GDP) (The Economist Intelligence Unit, 2017) and extensive poverty (Dobie, 2001; Huang et al., 2016a). Undoubtedly, poverty exacerbates the state of food insecurity (Hoddinott et al., 2012). Additional important determinants of food insecurity exist, including ineffective agricultural infrastructures and difficulties in accessing financing programs (The Economist Intelligence Unit, 2017), illiteracy and lack of education (Dobie, 2001), political instability and corruption (The Economist Intelligence Unit, 2017), as well as armed conflicts, violence, terror, and wars (FAO, 2016a).

In climatic terms, drylands are defined by a relatively low ratio between precipitation and potential evapo-transpiration (P/ETP). In semi-arid regions, this ratio ranges between 0.2–0.5, in arid regions, between 0.03–0.2 (Penman method, or 0.05–0.2 according to the Thornthwaite method), and in hyper-arid regions, this ratio is less than 0.03 (Penman method, or > 0.05 according to the Thornthwaite method) (Fig. 1). Drylands are also characterized with inter-annual rainfall variability or fluctuation, ranging between 20–25% in semi-arid regions, between 50–100% in arid regions, and exceeding 100% in hyper-arid regions (Bruins and Lithwick, 1998). Although climatic fluctuations are expected in drylands, climatic variability in recent decades has increased and includes rising temperatures, lower reliability of rainfall, and increasing frequency, duration, and magnitude of droughts, all of which impact food production. Future climate change scenarios forecast increased erratic and unpredictable climatic conditions (Davies et al., 2016). Furthermore, despite high spatiotemporal variability, global climatic models project increasing temperatures and decreasing precipitation in the lower latitudes, with the resultant dryland aggravation (Yirdaw et al., 2017) and expansion (Feng and Fu, 2013). A recent modeling study predicted that compared to the 1961–1990 baseline, the total area of drylands will increase by 11–23% by the end of the 21st century, covering 50–56% of the global land surface (Huang et al., 2016a). The adverse impact of climatic change on food security seems to be most significant for populations who directly rely on drylands' natural resources for their survival, such as pastoralists and agropastoralists.

Types of land cover across the globe's drylands include grasslands (31%), forest lands (18%), croplands (14%), wetlands (2%), settlements (1%), and other (34%). Of the dry-sub-humid lands, 22%, 43%, and 26% are grasslands, forest lands, and croplands, respectively. In the global semi-arid lands, the areal cover of grasslands tremendously increases (41%), and that of forest lands and croplands considerably decreases (20% and 19%, respectively). In the world's arid lands, the share of grasslands is similar to that of semi-arid lands (39%), but that of forest lands and croplands sharply decreases (5% and 6%, respectively). In the global hyper-arid lands, areal cover of the three types of land cover is small-to-negligible (5%, 1%, and 2%, respectively) (FAO, 2016b). Land-use change across the global drylands also affects food security, especially among pastoralists and agropastoralists who directly depend on rangelands for livestock. Driven by demand for construction material, fuelwood, charcoal, forest products and croplands, land-use change has resulted in landscape fragmentation, loss of access to grazing resources, deforestation, and vegetation clearing. Alongside long-term ecologically unsustainable grazing regimes, a large extent of land degradation across the world's drylands is attributed to the aforementioned land-use changes (de Waroux and Lambin, 2012; du Preez, 2014). Additional factors causing dryland degradation are the expansion of mining, heavy industry, infrastructures, and urbanization (Galvin et al., 2008; Liniger et al., 2008; Galvin 2009). As elsewhere, processes of dryland degradation include declining physical, chemical, and biological quality of soil, loss of soil organic carbon pools, soil erosion, soil salinization, the pollution of soil, water, and air resources (Liniger et al., 2008; Karlen and Rice, 2015), biodiversity loss, and the deterioration of a wide range of related ecosystem services (Liniger et al., 2008; du Preez, 2014; IPBES 2019). All these processes adversely affect food production, and therefore have negative consequences for food security.

Food security is dryland is also affected by demographic stressors. Human population in the worlds' drylands surpassed 2.6 billion in 2010 and is projected to increase by 40–50%, to around 4.0 billion, by 2050 (PBL, 2017). Yet, a global decline in fertility is forecasted; the current 2.5 births per woman is projected to decrease to 2.2 in 2045–2050, and to stabilize at the replacement level (2.0 birth per woman) or lower, by 2095–2100. The current ~ 7.5 billion global human population is projected to increase to 8.4–8.7 billion in 2030, 9.4–10.2 billion in 2050, and 9.6–13.2 billion in 2100. This trend is attributed mostly to a relatively youthful age distribution in LDCs, where the fertility rate and population growth continue to be relatively high (4.3 births per woman and 2.4% yearly). Among these, countries in the African and Asian drylands are projected to experience the highest rates of population growth; many of them are expected to double their size, but converge to replacement levels by 2095–2100 (UN, 2017a).

Migration is another important factor, which impacts population dynamics at either the country or regional level. Africa, Asia and Latin America are considered net senders, with the volume of out-migration generally increasing over time (UN, 2017b). The major causes for migration out of the drylands include environmental degradation, unemployment, poverty (Rechkemmer et al., 2016), wars, and other armed conflicts (UN, 2017a). Despite these migration trends, the projected population growth, coupled with increasing aridity and accelerated land degradation across the world's drylands, is expected to considerably exacerbate the environmental pressures and accelerate food insecurity in these regions. Particularly, these trends are mostly expected to jeopardize populations that maintain traditional livelihoods, such as pastoralists and agropastoralists.

The objective of this study is to explore some of the major factors that determine food security for pastoralists and agropastoralists, who constitute a considerable proportion of the total population in drylands. We acknowledge that these populations use other regions as well, whether meeting in sub-humid regions during the wet seasons or engaging in markets outside of drylands (Ayantunde et al., 2014). Yet, the focus of this paper is on people who dwell primarily in drylands. We include the entire spectrum of populations – ranging from nomadic pastoralists to settled/sedentary agropastoralists – whose livelihoods rely on a combination of livestock husbandry, agricultural cropping, and off-farm income-generating activities. The study was conducted by analyzing a wide range of technical reports, review studies, and cutting-edge case studies of the world's drylands. Within this vast topic, this study focuses only on the most direct factors affecting food security among dryland pastoralists and agropastoralists, namely climate fluctuations and change, land-use and management practices, and human population dynamics, as well as on the complex web of interrelations and feedbacks among these factors. Although many studies deal with some of these aspects, inclusive analyses of this topic are still scant, highlighting the need for such a comprehensive study. Due to increasing natural and anthropogenic pressures in drylands, this need has become urgent, necessitating the provision of structured information for policymakers, allowing judicious decision making to successfully confront these challenges. In the following sections, we assess how climatic changes, land management, and population dynamics affect the four pillars of food security among drylands pastoralists and agropastoralists.

Climatic variability and change

The climate system and food security are strongly linked; changing weather patterns strain the food system, and at the same time, the agriculture/livestock sector is a major contributor to greenhouse gas (GHG) emissions. Climate variability occurs on diverse timescales, ranging from monthly or seasonal to annual or inter-annual, and includes large-scale features such as the El Niño Southern Oscillation (ENSO), which affects rainfall and weather patterns (Fig. 2). Climate variability may be natural or influenced by anthropogenic factors, and is highly spatially diverse, especially in the drylands, with its consequences for ecological dynamics. An increase in global mean temperatures due to increased GHG emissions by anthropogenic activities has been observed for a number of decades (Stocker et al., 2013). The 2016 Paris Agreement aims to keep global mean temperature rise below 2°C and even limit temperature increase to 1.5°C, although focused mitigation actions will be required to achieve this goal (Rogelj et al., 2016). However, of potentially more importance is the associated change in frequency of extreme weather events, such as droughts, floods, heatwaves, and storms. Although extreme events have always occurred through natural processes, changes in their frequency, duration, spatial scale, and intensity are likely to increasingly disrupt food and water security, health, and infrastructures (Field et al., 2012).

The main risks for food security in drylands that arise from climate change and variability are due to changes in temperatures and rainfall patterns, and especially, the frequency of droughts and floods, and the intensity of extreme weather events such as tropical storms (Mbow et al., 2019). Changes in the timing of large-scale processes, such as monsoon circulations and sea-level rise, also have the potential to impact food security in coastal areas. Localized or regional changes, with seasonal variability, will make some areas more vulnerable than others, with a particular relevance for drylands, which will become drier (Stocker et al., 2013). Drylands and their food production systems are particularly sensitive to temperature and precipitation levels. Since drylands cover a large area of the earth, and since temperature and precipitation forecasts vary by region and latitude, climate change may affect tropical, subtropical, and temperate drylands in different ways (Schlaepfer et al., 2017). Although increased temperature and changes in precipitation patterns associated with climate change are likely to lead to dryland expansion in many regions (Huang et al., 2016a), they could reduce temperate drylands by around a third, and convert them to subtropical drylands (Schlaepfer et al., 2017).

Global observations show an increase in the number of warm days and nights (as well as a decrease in the number of cold days and nights) since the 1950s. Similarly, the number and length of heat waves have increased in many regions globally (Stocker et al., 2013). Over the last 100 years, the most intense warming was observed over drylands, accounting for over half of continental warming (Huang et al., 2017).

Model projections show a significant warming in temperature extremes by the end of the 21st century, with an increase in frequency and magnitude of warm days and nights as well as of heat waves. According to various emission scenarios, a 1-in-20 year annual hottest day is expected to become a 1-in-2 year annual extreme by the end of the 21st century in most areas. Depending on region and on emission scenarios, a 1–3°C increase in temperature is expected by the mid-21st century, and a 2–5 °C increase is expected by the late 21st century (Stocker et al., 2013). These trends may induce further expansion of drylands, resulting in an increase of the number of pastoralists and agropastoralists affected by water scarcity and land degradation (Huang et al., 2016b).

Projections of future precipitation levels are less certain than projections of future temperatures, and are greatly region-dependent. Globally, the number of heavy precipitation events (e.g. 95th percentile) has increased in many areas over the second half of the 20th century. However, strong regional, sub-regional, and seasonal variability exists, and many areas show unclear trends and even a decrease in extreme precipitation events (Stocker et al., 2013). In terms of future projections from both global and regional analyses, it is likely that the frequency of heavy precipitation events will increase in the 21st century over many areas of the world, including some (but not all) areas with projected decreases of total precipitation. Additionally, a range of emission scenarios show that the 1-in-20 year annual maximum 24h precipitation rate is likely to become a 1-in-15 to 1-in-5 year event by the end of the 21st century (Stocker et al., 2013). Although heavy precipitation events may increase in some areas, observations have shown increased aridity in drylands over recent decades, partly driven by increased evaporation due to higher temperatures. Observations further show that dry areas tend to become drier, while wet areas are becoming wetter (Feng et al., 2015). These trends are projected to continue in drylands, where shorter, less frequent, and less widespread precipitation events are expected (Giorgi et al., 2014).

Higher intra-annual variability limits precipitation to a small number of days per year. These extreme rainfall events have direct adverse consequences on the availability of pastures for livestock in drylands (Sloat et al., 2018) forcing both pastoralists and agropastoralists to travel longer distances to feed their animals, and to rely on purchased fodder and grains. Higher precipitation variability has negative consequences for the yield of crops cultivated by agropastoralists, adversely affecting availability of feed for livestock and causing losses in terms of livestock productivity (O’Leary et al., 2018).

Trends since the 1950s, showing more intense and longer droughts, have been reported in particular in southern Europe and West Africa. However, when attributing the changes in droughts to climate change at a single-region level, the confidence is low, because of insufficient and inconsistent evidence (Stocker et al., 2013). Future projections suggest increases in the duration and intensity of droughts in central Europe, southern Europe, the Mediterranean basin, central North America, Central America and Mexico, northeast Brazil, and southern Africa (Stocker et al., 2013). Specifically, droughts are projected to be more substantial in the world's drylands, where an increase in the length of dry spells is expected (Giorgi et al., 2014).

Although, as described above, there is great variation in the location and extent of changes, climate change could have a number of direct and indirect effects on all four main dimensions of food security, including food availability, access to food, utilization of food, and stability of these dimensions over time.

There are numerous ways in which climate change and variability affect crop production for food and fodder, pasture conditions, livestock health and productivity, and the pattern and balance of trade of food and food products (Wheeler and von Braun, 2013). Specifically, climate change and variability affect the yield of staple crops such as wheat, rice, maize, and soybean through weather-related impacts, as well as through changes in atmospheric carbon dioxide (CO_2) concentrations. Impacts of rising mean temperatures on crops have generally shown decreased yields (e.g. Lobell et al., 2011), especially in southern regions (Fallon and Betts, 2010). Furthermore, an increase in frequency and intensity of extreme rainfall events increases soil erosion (Vallebona et al., 2015; Burt et al., 2016). Crops are also affected by extreme temperatures; many crops are particularly sensitive immediately prior to or during pollination (Hatfield et al., 2011). While higher levels of CO_2 in the atmosphere can positively affect crop growth through the ‘CO_2 fertilization effect’ (Blumenthal et al., 2013), they also increase the competiveness of invasive weeds, which adversely affect crop yields and require farmers to spend more effort and resources in combating weeds (Ziska, 2016). Furthermore, although there is no conclusive evidence that climate change will increase infestation of pests and diseases globally, it will certainly shift their geographical distribution and seasonality (Stocker et al., 2013). For example, the outbreaks of desert locust in African drylands were suggested to be impacted by climate variability. Specifically, a positive effect on locust infestation was reported to follow exceptionally high rainfall events, which tremendously increase productivity of annual vegetation (FAO, 2016c).

Similarly, climate change can affect livestock production through its effect on the basic natural resources required for keeping animals, such as fodder and water (Baumgard et al., 2012). Impacts of climate change on livestock production also include productivity loss due to heat stress – particularly in already hot tropical drylands. Heat stress reduces dairy production, animal weight gain, and reproduction levels (Baumgard et al., 2012), and lowers resilience to diseases (Rojas-Downing et al., 2017). Additionally, floods, droughts and other extreme weather events can directly cause livestock mortality, for example, by drowning cattle. Such livestock losses from sudden-onset events can have a devastating impact on food security among pastoralists and agropastoralist households (Warner et al., 2013).

Access to food is strongly related to household and individual income, capabilities and rights. It is often modeled using a combination of interlinked climate, crop, and economic variables for simulating crop yields under different climate scenarios, although it does not capture climate adaptation measures (Wheeler and von Braun, 2013). The International Food Policy Research Institute's (IFPRI) International Model for Policy Analysis of Agricultural

Commodities and Trade (IMPACT) connects climate scenarios with food supply, markets, and price outcomes, and tracks the economic consequences of drivers to food availability, energy consumption, and children's nutritional status (Nelson et al., 2010). Access to food can be impaired by extreme weather events which affect food production, but also by storage and transportation challenges. Increasing food prices also impact availability, particularly for poorer populations in low-income countries, where people spend a larger proportion of their incomes on food (FAO, 2008b). Transportation and storage of agricultural supplies involve complex supply changes, which are vulnerable to climatic-driven hazards at all stages.

Utilization of food is strongly linked to access, and determines the nutritional status of individuals. The risk of extreme events requires public health services – notably limited in dryland areas – to help in preventing adverse health impacts. This includes surveillance and control for infectious disease, access to safe water, improved sanitation, maintenance of infrastructure, health care services, and food security (Keim, 2008). Nutritional well-being depends on water, sanitation, and diet composition and quality, all of which may be affected by several aspects of climate change, particularly floods and droughts (Mbow et al., 2019). It is particularly challenging to attain nutritional well-being among pastoralist populations who tend to be nomadic or semi-nomadic, and do not have year-round access to health services.

Furthermore, climate change affects food stability, since disruptive weather patterns pose a risk to long-term access and food security status, with considerable economic and political consequences. In many dryland areas, the economy is strongly linked to agriculture and may be dominated by small-scale or subsistence farming, where livelihoods of local populations are especially sensitive to weather extremes (Easterling et al., 2007). For the majority of households in drylands, home-scale produced crops are consumed by the households rather than being sold

(FAO, 2009), and there is limited capacity for recovery following extreme events. Climate change is seen as a major determinant for short-term fluctuations in food prices, as well as for future price trends. For example, the 2010 severe drought in Russia and parts of Europe caused severe damages to the wheat harvest, with the resultant restrictions on export and spike in prices (Wegren, 2013), which in turn caused socio-economic problems and political unrest in several African, Asian, and Middle Eastern countries. Similarly, the 2011 winter drought in eastern China had a serious economic impact in Egypt, the world's greatest wheat importer, and led to civil unrest (Sternberg, 2012). Similarly, droughts in other parts of the world, such as California and Australia, have put a strain on the stability of food supplies in recent years (Madadgar et al., 2017, Pathak et al., 2018).

Land-use and management practices

The management of arid and semi-arid rangelands and their tenure systems affect food security of human populations. These dryland areas, on which most of the world's livestock are raised (O'Mara, 2012), are predominantly managed by mobile pastoralists who greatly depend on the products of their domestic animals (camels, cattle, horses, and small ruminants) for food and income (Reid et al., 2014). Research on dryland ecology has established that mobile pastoralism, as a land management system, is well suited for drylands (Ellis and Swift, 1988). It is efficient and environmentally friendly, and provides nutrition and food security even under the most adverse environmental conditions (Galvin, 1992; Krätli et al., 2013). Across the world's drylands, livestock husbandry supports hundreds of millions of livelihoods and contributes to the global food balance (Herrero et al., 2009; Herrero and Thornton, 2013; van Ginkel et al., 2013; O'Mara, 2012).

For dryland pastoralism to be productive and sustainable, livestock must move. Common property regimes predominate in rangelands (Godde et al., 2018), allowing pastoralists to flexibly and strategically move their livestock across vast territories. This ensures that animals access temporally and spatially transient natural resources (water and forage) and achieve adequate nutrition, while avoiding hazards such as disease and conflict (Krätli and Schareika, 2010; Turner and Schlecht, 2019). Livestock movement, and the institutions enabling it – including communal land tenure, social norms of reciprocity, and social networks (Galvin, 2009; Turner et al., 2014) – are critical for the productive and sustainable management of rangelands (Turner, 2011; Turner et al., 2016). The transhumance systems of West Africa are a good example of the importance of local and regional mobility for pastoral and agropastoral socioeconomic status and welfare (Bassett and Turner, 2007; De Bruijn and Van Dijk, 2003; Turner et al., 2014).

Yet, governments and development organizations often bedevil mobile pastoralism as an irrational and inefficient land management system that causes environmental degradation and food insecurity. To prevent overgrazing and boost livestock productivity, top-down development initiatives – misguided by Hardin's argument that natural resources held in common inevitably get degraded (1968) – have sought to privatize land and resources, settle nomads, and intensify livestock production. In Africa, these policies have accelerated land degradation (Talbot, 1972) and livelihood insecurity (Fratkin and Mearns, 2003). Changes in rangeland use and tenure systems in past decades have generally been associated with decreasing food security, which is becoming a growing concern for dryland livestock producers, simultaneously challenged by increasing climatic variability (Herrero et al., 2016).

Research on food security in dryland grazing systems has focused mainly on two dimensions, i.e., the availability of food (livestock production) and its consumption by individuals (their nutritional status). Since the 1990s, the nutritional status of Sub-Saharan African pastoralists and agropastoralists has not improved (Galvin et al., 2015; Sellen, 1996), and Central Asian pastoral welfare has deteriorated (Fratkin and Mearns, 2003; Janes, 2010). In recent decades, the number of livestock units per capita that are necessary to ensure nutrition and health of pastoral households has been declining under growing climatic, demographic, economic, and political stressors (Coppock et al., 2017; Thornton et al., 2006).

Exposure to increasing perturbations caused by extreme climatic events or armed conflicts that affect the stability of their food availability, access, and utilization, has led many pastoralists to settle and/or diversify their sources of income and food, or abandon livestock production (Herrero et al., 2016; Pike et al., 2016). These pastoral livelihood dynamics are common throughout the Sub-Saharan African, Middle Eastern, and Central Asian dryland grazing systems (Coppock et al., 2017; Hadri and Guellouz, 2011).

Shifts in land-use and land tenure have affected livestock mobility, rangeland status, livestock productivity, and herd sizes, and, ultimately, food production, food security and pastoralists' welfare. Reviews by Galvin (2009), Reid et al. (2014), and Coppock et al. (2017) highlighted the roles of land privatization, pastoralist sedentarization, cropland expansion, farmer-herder conflict, protected area delimitation, and large-scale land grabbing and acquisition, in fragmenting rangelands and constraining animal mobility (see also Bukari et al., 2020; Turner et al., 2014; 2016) . The lack of legislation and policies supporting local and regional livestock movements, as in some countries of the Sahel, is another factor promoting more sedentary and less productive livestock husbandry (Gonin and Gautier, 2015).

These interacting processes, sometimes driven by the pastoralists themselves as their livelihoods diversify and aspirations change (Galvin, 2009), limit the access of livestock to heterogeneous and nutritious forage, and may increase disease infestation. This, in turn, decreases meat and milk production (McCabe et al., 2010), which may force herders to sell animals to buy food (Krätli et al., 2013). Limiting animal mobility also causes localized land degradation (Hobbs et al., 2008). Combined with pastoralists' needs for cash in increasingly market-based economies and their desire to access services, these processes have led them to diversify their income and food sources (Galvin et al., 2015; Thornton et al., 2006). This has unevenly affected their food security.

While there is vast literature on land-use change and livelihood transitions in Sub-Saharan African rangelands, only a few studies (most of them on east African livestock producers) have measured the effects of changed livestock mobility on pastoral food security, mainly focusing on household food utilization and individual nutritional status. Sedentarization of nomadic pastoralists, associated with a decreased reliance on livestock and economic diversification, resulted in malnutrition, especially among women and children in West Africa's Sahel (Pedersen and Benjaminsen, 2008) and in drought-prone northern Kenya (Galvin, 1988; 1992; Nathan et al., 1996; Fratkin et al., 1999; Fratkin, 2001; Fujita et al., 2004; Shell-Duncan and Obiero, 2000). Sedentarization also impacts access to meat and dairy products by separating between settled household members and their herds grazing in distant places, and by depressing milk production. Diets become poorer, even when supplemented with cultivated or purchased foods (Fratkin 2001). Studies in semi-arid East African environments, characterized by differential access to infrastructure, services, markets, and influence of biodiversity conservation policies, offer more nuanced analyses of the effects of reduced animal mobility on food security. Thornton et al.

(2006) modeled the effects of privatizing land held in common by Kenyan Maasai pastoralists into parcels of various sizes, as well as the effects of different economic strategies, on their food security. The model showed that settling on smaller parcels and losing access to dry season pastures decreases food availability, as pastoralists must decrease their herd size, and thus rely on fewer livestock for food. It suggests that future food security becomes compromised as people sell animal assets to purchase foodstuffs. Further, the simulated impacts of land subdivision also varied with type of farming and ecological conditions. Households with irrigated fields are expected to experience better food security than those with rainfed farms in drier areas. The model generally suggested that the most diversified households are nutritionally advantaged.

Ianotti and Lesorogol (2014) assessed food utilization by comparing micronutrient intake adequacies in Kenyan Samburu pastoralist communities undergoing livelihood shifts. The study examined whether differences in income, livestock holdings, and agricultural activity, caused by a shift from communal to private land tenure, explained differences in micronutrient intake. Overall, they found little evidence of nutritional differences associated with land privatization and cultivation. At the same time, income and ownership of livestock were positively associated with dietary diversity and nutrient adequacy. Independently of these communities' degree of sedentarization and economic diversification, milk and meat consumption was shown to be a critical source of micronutrients and a central element of local food security.

Similarly, Galvin et al. (2015) compared the nutritional status of Kenyan Maasai pastoralists across a gradient of land-uses, land tenure situations, and degrees of livestock mobility, and demonstrated that in a context where nutritional status is poor for all age and sex groups, pastoralists who lived on communal land, who farmed, and whose herds were more mobile, had slightly better nutritional status. This highlights that both livestock mobility and cultivation, as diversification strategies, improve food availability and utilization. Regarding access to food, their findings also suggest the importance of traditional practices of reciprocity, food sharing, pasture and animals, and social capital and institutions that facilitate livestock mobility (see also Goldman and Riosmena, 2013; Iannotti and Lesorogol, 2014; Pike et al., 2016; Turner et al., 2016). When assessing nutritional outcomes across several Tanzanian ethnic groups, Lawson et al. (2014) found, instead, that the nutritional status of Maasai pastoralists was worse compared to that of Maasai farmers. However, as acknowledged by the authors, the difference was not significant and could reflect the better health services available in the villages where people also farmed. Finally, where wildlife conservation policies restrict or prohibit livestock grazing inside protected areas, thereby limiting the availability of meat and dairy products, cultivation becomes critical for food security, as observed among the Maasai pastoralists living in the Tanzania's Ngorongoro Conservation Area (McCabe, 2003).

In the Middle East and North Africa (MENA) region, drastic transformations of rangelands have affected livestock mobility and traditional norms of pasture management, resulting in land tenure uncertainty and possibly reducing food security. In particular, the nationalization of communal lands has created situations in which access to pastures is unrestricted, leading to widespread land degradation. Provision of water sources and government subsidized supplemental livestock feed have exacerbated the issue by allowing pastoralists to retain excessive numbers of livestock during droughts, further degrading rangelands (Hadri and Guellouz, 2011). While food insecurity is not yet a serious threat in MENA drylands, concerns are rising because of climatic change, water stress, population growth, political instability, and dependence on imported food (Zdruli, 2014).

Food insecurity in the Central Asian rangeland areas is not widespread (Coppock et al., 2017). However, land tenure shifts also impact pastoralists' wellbeing. Unlike in the Middle Eastern rangelands, post-Soviet decollectivization, featuring privatization of livestock and quasi-privatization of pastures, has created open-access situations, and increased inequality and competition among livestock producers (Reid et al., 2014). Among Mongolian pastoralists, worsening nutritional and health indicators (Janes, 2010) suggest that the 1990's transition to a market economy, coupled with weakening governance of state-owned communal grazing resources, has impaired food security. Because government leases favor wealthier and more powerful households, poorer herders have lost access to pastures and have become food insecure (Janes, 2010). Other drivers of livelihood insecurity in Mongolian rangelands include reduced livestock mobility, overgrazing, and land degradation (Sternberg, 2008).

Finally, at the global scale, food and energy security concerns of actors located outside of drylands are emerging threats to the food security of dryland dwellers. Large-scale land acquisitions (LSLAs) for commercial agriculture by foreign governments and corporations are driving direct and indirect land-use change, cropland and pasture alienation, and displacement of local communities (Galaty, 2013; Koizumi, 2015; Schlee, 2013; Bukari et al., 2020), thus adversely affecting their food availability and access. Pastoral rangelands' common property regimes make them particularly vulnerable to such land grabs (Dell'Angelo et al., 2017). In addition, transportation infrastructures associated with mega-development projects (e.g., mining, energy production, etc.) have also fragmented dryland ecosystems, thus adversely impacting the provision of ecosystem services, animal mobility, and pastoralism (Mosley and Watson, 2016; Ascensão et al., 2018). Future research should analyze the costs of these processes for rangeland residents' food security.

One way or another, food security is notoriously difficult to measure (Holden and Ghebru, 2016). Variations in ecological and socioeconomic characteristics within and between dryland communities (Shell-Duncan and Obiero, 2000), as well as the complexity of the interconnected challenges affecting livestock production, and people's access to food and nutritional status, make it difficult to generalize what determines current states of food (in-) security. Long-term studies on food security and health consequences of livelihood transitions in dry rangelands are therefore crucially important (Lawson et al., 2014).

Human population dynamics

Three aspects are considered central in assessing the effect of population dynamics on food security in drylands (Geist and Lambin, 2004; Cherlet et al., 2018): (a) population size and growth; (b) urbanization; and (c) population mobility. In turn, food security affects population dynamics. For example, Neumann et al. (2015) listed food security among the macro-level drivers of migration in drylands, while a recent FAO report (FAO, 2018b) linked food insecurity to negative health outcomes such as low birth weight and stunting in children, as well as under-nutrition and obesity. In the worst cases, famine may result in increased mortality. Population size and growth are key determinants of the impact of demographic trends on food security in drylands, particularly on food availability, and this effect is expected to continue in the near future (FAO 2018a), amplified by the expected negative impact of climate change on food production in drylands (as described in the section on climatic variability and change).

Populations living in drylands are also expected to increase due to the expansion of drylands (Feng and Fu, 2013). Projections of dryland expansion and of population growth in drylands depend on the level of warming in the models. From the baseline of 2.6 billion people in 2010, a global warming of 4 °C (2068–2081) would result in a drylands population of between 3.3 (more favorable scenario) and 5.2 billion people (more pessimistic scenario) (Koutroulis, 2019). This range reflects different population projections under the Shared Socioeconomic Pathways (SSPs), which are storylines that describe projected socio-economic trends such as population growth and distribution, economic growth, and land cover (Jones and O'Neill, 2016; 2017).

Projections of population change in drylands between 2010 and 2050 (obtained from PBL; Population projections in drylands: https://www.pbl.nl/en/infographic/population-growth-in-drylands) under the SSP2 scenario, including population in new drylands, indicate considerable regional variation. SSP2 – named "middle of the road" scenario – is characterized by medium population growth, medium economic growth, and medium technological change, in other words, current trends are continued (van der Esch et al., 2017). Overall, dryland populations may increase by 40–50%, while increase in non-drylands would be around 25%. In terms of regional differences, South Asia displays the largest increase in absolute numbers (about 500 million, an increase of 53%); the Sub-Saharan Africa's population is projected to double (from 371 million to 542 million); and an increase of 60% is projected for the MENA region (from 373 million to 597 million). At the same time, population decline is projected for other dryland regions, including these in China (-17%, from 468 to 388 million), Russia and Central Asia (-5%, from 163 to 140 million), and Southeast Asia (-91%, from 19 to 2 million) (van der Esch et al., 2017: Table 5.1).

Moreover, natural increase (births minus deaths) tends to be higher and human well-being lower among drylands populations (de Sherbinin et al., 2012; UN, 2010). While fertility is declining, projected population growth is reinforced by population momentum, which itself is a function of the very young age structure of many dryland countries, especially those in sub-

Saharan Africa (e.g., Andreev et al., 2013). Declining fertility and increasing life expectancy will also modify the age composition of drylands population (for example, accelerated aging (e.g., Barbieri et al., 2010)), which is likely to change food demands and consequent food utilization.

Economic development may further amplify the effect of population growth and composition changes on food security. Higher incomes increase the demand for food. For example, FAO (2018a) projected that by 2050, demand for food will increase by 50%, while the 'nutrition transition', which refers to shifts in diets to include more meat, high-energy food products, fats, added sugars or salt, and less or inadequate consumption of vegetables, fruits, and dietary fiber (FAO, 2017), will alter demands for food (Suweis et al., 2015; van der Esch et al., 2017). These changes would impact not only the availability of food, but also the utilization of food.

A second important driver of population dynamics in drylands is population distribution and urbanization. To begin with, population distribution in drylands is very heterogeneous, and one of the factors is local variations in water availability, directly related to degree of aridity. Population density tends to increase as aridity decreases, ranging from about 10 people km^{-2} in hyper arid regions to almost 70 people km^{-2} in the dry-sub-humid areas (UN, 2010).

The largest factor related to population distribution is urbanization. Drylands include a substantial proportion of the global urban population, with considerable regional variations. At the end of the 20th century, about half of Africa and India’s urban residents were in drylands, but percentages were much lower in South America and China (Balk et al., 2009). Yet, drylands are not as urbanized as coastal regions, though their urban populations are nevertheless increasing (de Sherbinin et al., 2012).

Projections of urban populations into the next decades indicate that percentages of urban population will continue to grow while maintaining regional variations. China, already 55% urban in 2015, is projected to reach 80%, while Central, South, and Southeast Asia are expected to be around 60%, 54%, and 66% urban, respectively, by mid-21st century (UNDESA 2018). Sub-Saharan Africa is expected to be 58% urban by 2050 (up from 39% in 2015), narrowing the gap with Northern Africa (64% by 2050, up from 51% in 2015).

As with economic growth, increasing urbanization is linked to higher food demand and shifting consumption patterns, a trend expected to continue (FAO, 2018a), and these patterns may affect the pillars of availability and utilization of food. At the household level, urban and rural households may present different vulnerability to food insecurity: food access may be easier in urban areas, while food availability is the more relevant pillar in rural areas (Crush and Battersby, 2016). At the country level, urbanization rates are negatively correlated with food security, though the relationship is dependent on level of development; African countries under rapid urbanization are more likely to be affected by food insecurity (Szabo, 2016). This could be the case for several dryland countries.

All four pillars of food insecurity need to be addressed differently in urban settings. For example, for the case of African cities, Battersby and Crush (2016) emphasized that food insecurity is rooted in structural poverty, market structure, policy issues, differential affordability of foods, and inadequate urban infrastructure at the city and household levels (e.g., inadequate storage, refrigeration, and cooking technologies).

The third important driver of population dynamics is population mobility. Migration is often viewed as a consequence of food insecurity (e.g., Nawrotzki et al., 2016; WFP, 2017), but it is also a key determinant of population dynamics in drylands: rural-urban migration is at the root of urbanization processes and it also influences population growth patterns. Globally, people seem to be moving out of drylands (de Sherbinin et al., 2012), but in some regions, urban areas in drylands are a destination (e.g., Barbieri et al., 2010). Migration is a key livelihood strategy in many dryland regions. For example, in West Africa, seasonal migration has been a strategy to reduce the number of mouths to feed in rural households during the dry season while also increasing household income (van der Land et al., 2018).

Drivers of in- and out-migration from drylands include inter- and intra-annual changes in water availability (including droughts) and land degradation (particularly losses in productivity) (de Sherbinin et al., 2012; Wiederkehr et al., 2018). Recent studies seem to indicate that land degradation (as a livelihood constraint) may be more relevant than water availability in certain contexts (Neumann et al., 2015). Of course, mobility strategies are important (e.g., Barbieri et al., 2010) but are not the only adaptation strategy households employ. Growing crops, breeding livestock, and management of soil and water resources are often more important (Wiederkehr et al., 2018)

Future scenarios of international migration indicate that the number of migrants will continue to rise, until peaking in 2040–2045, then decline due to population aging (Sander et al., 2013). Africa, Asia and Latin America will continue to be net senders, while Australia, Europe, and North America will be net receiving regions, with some exceptions. For example, oil-rich Middle Eastern countries (particularly the Gulf countries) receive substantial inflows of international migrants, usually on a temporary basis. Internal migration is also a considerable component of population redistribution through rural-urban migration, urban growth, and rural depopulation. In particular, it is agreed that mobility to other rural areas or to cities could be considered a form of adaptation to deal with changing contextual conditions, including climate and markets. A recent study in Mexico, Central America, East Africa, and South Asia reported that alongside economic development, climate change is likely to increase internal migration until 2050, and that communities relying on rainfed agriculture will face an increasing likelihood of out-migration (Rigaud et al., 2018).

Overall, population mobility in general (in its different forms, including internal, international, long-term, and temporary) is likely to affect food security in drylands. It could affect food availability directly (by increasing demands in destination areas and reducing them in origin areas) and indirectly (by affecting food production through the reduction of work force in rural areas). Migrants, particularly recent ones, could lack proper access to food, particularly in times of scarcity, and their adoption of new consumption patterns could also modify food utilization. Finally, the summary of these impacts could result in short-term food instability not only for migrants but for host and origin communities as well.

Specifically, pastoralist and agro-pastoralist populations are affected by and contribute to population dynamics in drylands. It is generally estimated that pastoralists number between 100 and 200 million worldwide, however reliable data is lacking. Some estimates suggest that as many as 500 million (including nomadic communities, transhumant herders, and agropastoralist) may inhabit the world's drylands, 268 million of them in Africa alone (Mbow et al., 2019; African Union, 2010). Overall, population growth of pastoralists and agro-pastoralists tends to be high (e.g., about 2.5 to 3.5% in Africa), and their global population is expected to double by 2050 (McGahey et al., 2014).

Increasing integration of livestock trade markets, diversification of livelihoods that benefit from being closer to urban centers, and availability of better services have accelerated urbanization in pastoral lands. Pastoralists and agro-pastoralists easily become urbanites, both in large urban centers and small towns, and this trend is particularly intense among the younger generation (McGahey et al., 2014; African Union, 2010; Ayantunde et al., 2011; McLeman, 2017). It has been acknowledged that moving to cities often increases food insecurity (Stites, 2020).

Urbanization trends are necessarily linked to changes in traditional mobility patterns. Mobility (nomadism or seasonal movements) has always been a part of pastoralists' and, to a lesser extent, agro-pastoralists' livelihoods (FAO, 2018c), but this is changing rapidly. All over the world, pastoralists are becoming more sedentary, and are switching to agro-pastoralism and sedentary farming. Migration (whether temporary or permanent) to urban areas or to other rural areas is common; many search for jobs, services, and amenities abroad. There are several factors that affect these processes, among them economic marginalization, land degradation, fragmentation of grazing lands, national sedentarization policies, and lack of educational and health services (McGahey et al., 2014; African Union, 2010; McLeman, 2017).

Synthesis and conclusions

This review study addresses how climate, land-use, and population dynamics affect food security for dryland populations. Figure 3 summarizes each of the three drivers that ultimately affect food security. Each driver of change impacts both social and ecological systems in specific ways. Impacts, in turn, have consequences for all food security components, including availability, access, utilization, and stability of these three conditions. Though changes in climate, land-use, and populations may have positive or negative effects, literature suggests that for drylands, most of the changes have adverse impacts on the socio–ecological system, which cascade into all components of food security.

There are strong interlinkages among the drivers that affect food security (Fig. 4). Each of the drivers of climate change, land-use change, and population dynamics affect drylands and people to different degrees. Generally, they have negative effects on food security. This is because the environmental, economic/political, and social impacts converge through similar processes in detrimental ways. For example, while clean water and healthy rangelands are fundamental to supporting food production, the latter is altered due to climate change. Health and diversity of crops and livestock directly affect food security. Planning, design, development, and management of human settlements affect the environment primarily through land fragmentation, and subsequently change pastoral and agropastoral land-use, land tenure, and mobility. In turn, these processes affect food stability. Ecological degradation due to changing land-use and climate increases outbreaks of pests and plant and livestock diseases. As a result, food access and utilization may change. Thus, the interlinkages among climate change, land-use change, and population dynamics must be acknowledged and considered when planning for food secure, resilient communities of the world's drylands.

Drylands are home to some of the poorest and least food secure peoples. They are often remote, politically and economically marginalized, and have limited access to markets, information, and services (Tucker et al., 2015). Further, formal institutions are typically underdeveloped, with land and water resources often insecure and unequally distributed. Thus, they are often systemically excluded from key resources, governmental programs, and support services. These structural weaknesses undermine development of resilient strategies to cope with global changes (Pelling et al., 2015). The factors that converge at the center of food security (Fig. 4) – including policy, infrastructures, markets, livelihoods and income, resource-use rights, and environmental degradation – all constrain pastoral and agropastoral communities to respond to the impacts associated with climate change, land-use change, and population dynamics.

Although positive change can be challenging, it can be facilitated through better collaboration and improved access to resources and infrastructures, such as information and markets. Diverse partnerships and networks that include different worldviews and values are required to embrace the socio-ecological complexity that Figure 4 demonstrates. Networks to share scientific information and indigenous knowledge between communities, researchers, and policymakers through new information pathways, e.g., mobile technologies, can leverage the inherent adaptive capacities of dryland peoples (Butt, 2015). Enabling conditions for effective governance to current changes requires multilevel institutions. This is because the scales at which the drivers of change take place are often different. For example, land-use change often causes fragmentation of drylands at local scales. At the same time, establishment of institutions that rebuild landscape connectivity requires management systems that operate at a larger scale (McAllister et al., 2006; Galvin et al., 2008). Positive changes in food security are likely to prevail when they honestly involve dryland peoples, when barriers are truly addressed, and when they balance present needs and projected future conditions.

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Figure captions

Figure 1. The world map, with global drylands distribution

Source: FAO (2021)

Figure 2. Temporal scales of climatic/meteorological variability

Notes: Dryland pastoralists and agropastoralists are subject to climate and weather-related variability over different timescales, which may impact their food security. This variability ranges between short-term meteorological events (e.g., extreme weather over days to weeks), through larger-scale weather and climate patterns (take place over months to years), and regional or global climate change (over several decades).

Figure 3. Drivers of food security, their impacts, and consequences

Notes:

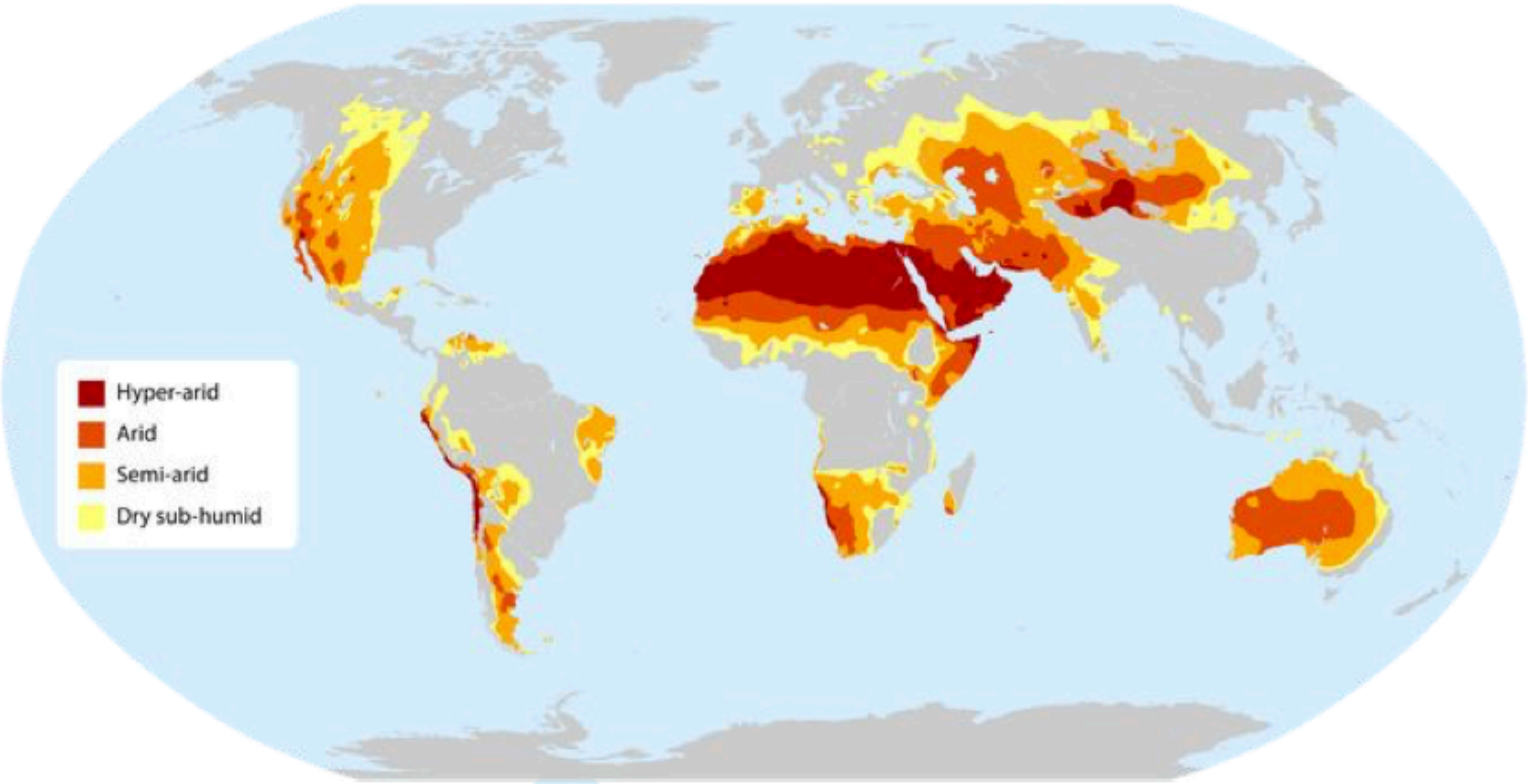
(A) shows that climate changes manifest themselves primarily through increased variability in patterns of rainfall. Seasonality also changes and extreme events (droughts and floods) occur more frequently. Temperatures trend upward in drylands. Both the social/economic/political system and ecological system are impacted. Crops and livestock are affected by disease, and heat and water stress, while landscapes suffer changes such as increased soil erosion and the spread of invasive species. People are impacted through changes in household incomes, instability of markets and prices for goods and services, and infrastructures are disrupted often by extreme events. Land tenure and land-use rights may change as governments invest in development that affects local communities. Further, individuals and households must deal with a decline in water availability and quality that in turn affects health and diets. Cultural losses may occur due to the need to migrate, for instance. Food availability from crops and livestock tend to decline. Increased prices and transportation costs affect food access and utilization, resulting in declines of nutritional and health status.

(B) presents land-use change as a major driving force affecting food security in drylands. Changes in sedentarization and urbanization, conversion of grasslands to crops, expansion of protected areas (nature reserves), and extractive land-uses (mines and quarries) occur throughout the world’s drylands. Consequently, infrastructure development fragments these landscapes with roads, powerlines, pipelines, fences, settlements, irrigation, etc. Land-use change has both ecological and social/political/economic impacts. It is difficult for livestock (and wildlife) to pass through fragmented landscapes. Changes in water availability (too little or too much) and plant composition lead to crop and livestock diseases that do not normally occur in drylands (e.g., blue tongue disease in sheep). New markets, volatile prices, and unstable industry often affect land tenure and increase the potential for conflicts. Society is affected by new demographic patterns such as urbanization, with associated new forms of wealth and inequality. All dimensions of food security may be affected through changing yields, food prices, and economic and political conflicts.

(C) demonstrates how population dynamics affect food security in unique ways including through population growth, increased urbanization, and changes to mobility. Urbanization and population growth are a cause and result of both policy and economic change. Infrastructures, markets, and prices affect households' income, population composition, urban density, and consumption patterns. These in turn shape human health and fertility patterns. Declining land and water availability, and land degradation processes, disturb the environment. Food security can be disrupted through changes in food production, changes to diet composition, and political and economic factors.

Figure 4. The climate, land-use change, and population nexus

Notes: the figure shows the connections that link the three drivers of dryland change. It demonstrates a constellation of factors that, in any particular combination, can work together to engender food insecurity. Climate change is represented by its own particular characteristics – temperature and precipitation changes, for example – as well as by increasing their variability. Land-use change is characterized by land conversion, while the changes associated with population dynamics are illustrated by increasing population and urbanization. Common elements are represented by overlapping areas. Climate change and population dynamics interrelate where there is increased water and food demand, increased need for market access, and disease outbreaks. Climate change and land-use change join to detrimentally affect land in terms of erosion and degradation, pasture management, and livestock disease, as well as increasing land privatization. Land-use change connects to population dynamics through land conversion and degradation and water loss, and via high food prices. Land tenure changes force migration and increase the potential for conflicts. The individual circles converge on food security at the center of the diagram. The effects on socio-ecological systems, such as reduced ecosystem productivity, and decreased livestock and crop productivity, affect food availability and stability. Government policy failures affect rights to natural resource use and access, and shape food access and utilization. Collapse of infrastructure and market changes (e.g., prices, types of food) decreases incomes of pastoralist and agropastoralist households and lessens their food access. The results of the nexus of drivers and impacts are risks to food security for extensive populations across the world's drylands.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