Characterizing the effect of drought, conflict, and locusts on food security in Africa

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Characterizing the effect of drought, conflict, and locusts on food security in Africa

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Conflict, drought, and locusts have been leading concerns for African food security in recent years, but the relative importance and spatiotemporal scales of crises resulting from each hazard is poorly characterized. Here we use continuous, subnational data from Sub-Saharan Africa to characterize how food crises differ according to livelihood strategy in response to each hazard. We find that when exposed to drought, pastoralists experienced more widespread, severe, and long-lasting food crises compared to those in agricultural zones. From 2009-2013 drought was the primary trigger of food security crises in all non-riverine zones; after 2013 conflict-related food security crises become prevalent. The few confirmed famines coincided with both conflict and drought. Locusts had little effect on food security during this time. These results provide multidimensional empirical evidence of how hazards affect food security in different livelihood zones, which provides an opportunity to improve scenario development in food security early warning forecasts.

The Famine Early Warning System Network (FEWS NET) estimates that 113 million people required emergency food aid across the 46 countries that it monitors during 2020[1]. This number has been rising since 2015, when just 48 million people were estimated to be in need. The deterioration of food security since 2015 is a concerning reversal of decades-long progress towards reducing both the number of people and percent of the global population that is undernourished[2]. This trend is particularly concerning in Africa, where the prevalence of hunger is highest and continues to increase[2].

In 2020, food security conditions in Africa were threatened by factors including possible export restrictions in Asia, violent conflict in South Sudan, flooding throughout the Sahel, drought forecast in the Horn of Africa, and desert locust swarms destroying crops across East Africa. How and whether these stresses led to food security crises depends critically on the ways that governments, markets, social networks, and humanitarian aid organizations manage the stress put on food systems. Nevertheless, each of these stresses threatens food security via distinct pathways, at different spatial and temporal scales, and may affect different populations. Understanding the characteristics of each stress is critical to formulating effective responses that prevent food security crises from developing.

Recent and ongoing food crises in Africa demonstrate that among the many possible stresses, drought, violent conflict, and locusts are three leading concerns. In 2019 and 2020, the largest desert locust outbreak in decades swarmed over East Africa. A landfalling cyclone in Oman produced warm, wet, sandy soils ideal for locust breeding[3], while political instability made accessing regions to control swarms difficult. It is estimated that locusts damaged hundreds of thousands of hectares of cropland and over a million hectares of pasture, raising the potential for food crises in both farming and herding communities [4]. The locust outbreak exacerbated stress due to ongoing drought and violent conflict - important factors in recent regional food crises. Maxwell and Hailey (2020), for example, use hundreds of interviews to identify drought and conflict as the primary triggers of the two confirmed famines, one likely famine, and two averted famines in Africa since 2010[5]. Analyses of food security crises that do not rise to the level of famines have likewise found drought and violent conflict to be central to recent food security crises in Africa [6–14]. The confluence of these three factors represents a grave challenge to food security.

Formulating an effective response, however, requires understanding the relative importance of locusts, drought, and violent conflict, as well as the spatiotemporal scales of associated food crises, in the context of different livelihood strategies, which is currently lacking. Here we analyze how conflict, drought, and locusts affect food security over the last decade by assessing the ways that pastoral, agro-pastoral, agricultural, and riverine or coastal livelihoods are exposed to, and affected by, each hazard in fourteen countries comprising East, West, and Southern Africa. Livelihoods here are defined as the ways in which a population accesses food or income to purchase food. Using the lens of livelihoods allows us to differentiate the effect of each hazard on different populations in a manner consistent with the practices of agencies tasked with responding to food crises[15]. We measure food security crises using the four dimensions of magnitude (the number of people affected), severity as measured by the Integrated Food Security Phase Classification (IPC) level, spatial coverage, and duration of the resulting food crisis[9] Our results provide insights that can better inform how food assistance needs may evolve differently in each livelihood zone in response to drought, conflict, or locusts.

Food crises disaggregated by livelihood Food insecurity in the fourteen included FEWS NET countries from 2009-2018 represents the least food secure countries in Africa. The FEWS NET countries include $\sim$70% of the population affected by hunger in Africa as estimated by FAO over this time period[2] with similar temporal trends between hunger in Africa and crisis level food insecurity (IPC $\geq$ 3) in the studied countries (Fig. 1a). The prevalence of food insecurity was consistently highest in pastoral livelihoods, with multiple periods of crisis level food insecurity affecting 40-50% of the pastoral population. Agro-pastoral, agricultural, and riverine or coastal livelihoods, on the other hand, tended to experience events in which crisis levels of food insecurity affected 10-15%, 5-10%, and 2-4% of the population in each livelihood zone, respectively (Fig. 1c-f). The prevalence of crisis levels of food insecurity has increased across all livelihoods since 2014. To understand what causes food insecurity in each livelihood zone, we will analyze the hazards to which each zone is exposed and the response of food security to those hazards.

Exposure of livelihoods Pastoralists not only experience more frequent crisis levels of food insecurity compared to other livelihoods, they were also exposed to more variable hydroclimate conditions, more frequent conflict, and are more frequently exposed to locusts (Fig. 2). Pastoral and agro-pastoral livelihoods in nearly every country were associated with more variable hydroclimate (Fig. 1b, 2b) while increased levels of conflict tended to be in East Africa and locusts were most prevalent in the Sahel. More variable hydroclimate conditions in pastoral areas likely indicates that these areas are unsuitable for purely sedentary agricultural livelihoods.

Vulnerability of livelihoods The relationship between food insecurity and drought or violent conflict differed by livelihood strategy (Fig. 3). Here we assess vulnerability to a hazard as the severity of food crisis that is associated with exposure to that hazard. More severe levels of food insecurity in pastoral and agro-pastoral zones were associated with drier conditions in the preceding year, while the relationship in agricultural and riverine or coastal zones was less strong. Crisis levels of food insecurity in pastoral zones overwhelmingly co-occurred with preceding dry conditions. These results agree with those of Coughlan de Perez et al. (2019) who demonstrate that droughts in East Africa affect pastoralists more strongly than non-pastoral livelihoods[16].

Severe levels of food insecurity were associated with more frequent conflict, most strongly in agricultural livelihood zones (Fig 3g; note differing y-axis) followed by agro-pastoral and riverine or coastal zones. The relatively few instances of famine-level food insecurity occurred during times of both conflict and drought (Fig. 3, SI Fig 1), which is consistent with research finding that the presence of conflict can make populations more vulnerable to subsequent shocks, such as drought[17].

Adult locusts were more frequently present during relatively food secure years, even after accounting for their increased presence in non-drought years (Fig. 3; SI Fig. 1). This increased frequency may be a result of locusts seeking out healthy crops as a food source, but the lack of association with food security implies that while extreme numbers of locusts may affect food security at a regional scale, they have not played a leading order role over the past decade. We use information on the presence of adult locust in this analysis, but we tested the sensitivity of using locust swarms, of which there were considerably fewer observations, and found that they too were disproportionately present in pastoral areas and showed no relation to food security status (results not shown). We caution, however, that the intensity of locust swarms during the 2009-2018 period did not reach the intensity of the 2019-2020 locust swarms, leaving open the possibility that locusts in extreme numbers may still affect regional-scale food security.

Duration, extent, and magnitude of drought-related food crises Differences in the relationship between food security and drought are not limited to the severity dimension of food crises. We find that, when exposed to droughts of a similar spatial extent and relative magnitude, a greater percent of pastoralist area and population entered crisis levels of food insecurity as compared to other livelihoods. In Pastoralist areas $\sim 40\%$ of the area and $\sim 60\%$ of the population reached crisis levels of food insecurity compared to 15-20% of both population and area in other livelihood zones (Fig. 4).

The time evolution of food insecurity differed significantly as well. Food security deteriorated more slowly in pastoral livelihood zones as compared to agricultural livelihood zones, and food insecurity persisted for longer. It took two years from the onset of drought to return to pre-drought levels of food security in pastoralist regions, while in agricultural livelihood zones food security improved more quickly following the return of normal rains. This discrepancy was particularly visible in the associated crude death rates for each livelihood zone. In pastoral livelihood zones death rates gradually increased for about 9 months followed by a gradual decrease for 12-15 months back to levels comparable to those at drought onset. In agricultural livelihood zones a sharp increase in the crude death rate for 3-6 months was immediately followed by an equally precipitous decrease, indicating a more severe hunger season than normal preceding harvest of the next crop. This suggests that at regional scales droughts do not generally disrupt planting a new crop significantly enough to trigger widespread food insecurity in agricultural livelihood zones. Riverine or coastal livelihoods showed little increase in the crude death rate in response to drought.

Market prices of staple foods were likewise higher following droughts compared to the expected seasonality of food prices as illustrated by the subsequent non-drought years. While food price data at local markets were not dense enough to disaggregate by livelihood zone, Figure 4 illustrates country-average prices for those countries containing each livelihood zone. Food prices peak coincident with the maximum extent of total precipitation or soil moisture deficits over the previous year. Crude death rates across livelihoods, which are derived from IPC data following Maxwell (2020), similarly peak coincident with drought and market price peaks.

While we considered that observed relationships between drought and food security may be confounded by relations between drought and conflict, we found no systematic relation between drought and either the frequency of conflict or deaths related to conflict (SI Fig. 2). Conflict may be affected by environmental stress in some cases but the relationship across Africa in recent decades is complex and context specific[18–21].

Attributing food security crises to drought and conflict Food insecurity as measured by either population or spatial extent is concentrated in just a handful of countries, and coincides with intermittent droughts and an increase in violent conflict (Fig. 5a,b). There is neither a trend towards drier soils across the study region (Fig. 5d) nor a trend in the percent of the population affected by drought (Fig. 5c). Conflict, however, has become more frequent in nearly all locations, with the largest populations affected in Nigeria and Ethiopia. Both the extent of conflict and the percent of the population affected by conflict are concentrated in Sudan, South Sudan, Ethiopia, Nigeria, and Somalia (Fig. 5e,f). While exposure to drought remained relatively constant, food security crises trended downward until 2014, after which time they have been increasing (Fig. 5c,e). The early part of the record includes large food insecure populations in Kenya, Somalia, and Ethiopia, followed by a rise of food insecurity in Nigeria and South Sudan after 2014 (Figure 5a,b). The only statistically significant trends towards worsening food crises - those in northeast Nigeria and South Sudan - co-occurred with increases in violent conflict. But in other states, such as Ethiopia, Somalia, Mali, and Sudan, significant trends towards more frequent violent conflict were not associated with trends towards food insecurity (Fig. 5). These findings highlight that while armed conflict is associated with negative effects on food security (Figs. 1 and 3), the effect can vary depending on the duration of the conflict and how it transforms local institutions and livelihoods [20–23].

To estimate the relative importance of drought or conflict in each country, we perform a maximum covariance analysis on a country-by-country basis (see Methods), which identifies how spatial patterns in drought and conflict vary synchronously with spatial patterns in food security. Figure 6 illustrates an example for the first mode for Somalia. This mode attributes food insecurity to a combination of drought and conflict, in agreement with past research demonstrating that protracted conflict and adverse economic conditions made the population of Somalia vulnerable to drought in the 2010-2011 and 2017 food crises, which disproportionately affected minority and marginalized groups[5,7–9,24,25]. There is a clear spatial association of drought metrics (Figure 6 c-e) with food insecurity (Figure 6a-b), with both most intense in south central Somalia. In central Somalia there is also an association of food insecurity with increased conflict (Figure 6f-g); in early 2011, for example, central Somalia was both the only area in a food crisis and the only area simultaneously experiencing drought and violent conflict. Elsewhere in Somalia drought-driving is dominant with food insecurity actually occurring with reduced conflict. The time variation (Figure 6i) describes drought-related food insecurity in 2010, 2011 (which reached famine), and 2017. The persistence of violent conflict during the drought in 2011 further contributed to the late and insufficient humanitarian response in some areas owing to operating restrictions imposed on relief agencies and the fear of food aid being diverted by Al-Shabaab[7,8,25]. The number of security incidents in Somalia, however, actually peaked in 2013 and 2014 and was lower during both major droughts of 2010-2011 and 2017[24].

Drought in Ethiopia is the dominant contributor to African food insecurity in the 2009-2013 time period, while in the 2014-2018 period conflict in South Sudan and Nigeria became important as well (Fig. 5, Fig. 7). Food security crises in Ethiopia and Kenya were primarily triggered by drought - with droughts straining food systems in parts of Ethiopia nearly every year, including major events in 2009, 2011, 2015 and 2017[10,26,27]. These droughts acted on populations made vulnerable by land fragmentation, lack of land tenure, lack of infrastructure, political marginalization, and armed conflict[10,11]. In Nigeria, by contrast, violent conflict was the primary trigger of food security crises (Fig. 7). The northeastern state of Borno is the epicenter of violent conflict related to Boko Haram, which has disrupted livelihoods, displaced people, and reduced households' ability to access food[12–14], while resource-related conflict in the central northern part of Nigeria has led to increasingly frequent farmer-herder conflicts and cattle theft [14]. Conflict furthermore affected food prices after 2016 (SI Fig 3) when oil pipeline sabotage in the Niger Delta reduced national oil production by over 50%[28]. In southern Sudan and South Sudan the recent increase in food insecurity is attributable in part to a sustained increase in violent conflict and in part to erratic rains from 2017-2019[9,20,29]. Armed conflict disrupted food production directly, but also disrupted oil production, which led to a collapse of government revenue, an increase in currency printing, and high levels of inflation[30](SI Fig. 3). It is notable that the two confirmed famines during this time period - South Sudan in 2017, and Somalia in 2011 - occurred in the presence of both drought and conflict (SI Fig. 1).

Over the entire study period, drought became slightly less important as a source of food insecurity, while conflict became relatively more important (Fig. 7). The change was particularly pronounced in Agricultural livelihood zones due to the simultaneous increase in conflict-related food insecurity in Nigeria and the decrease in drought-related food crises in Ethiopia. In Pastoral and Agro-pastoral zones a more modest relative rise in conflict-related food insecurity was attributable to the rise in violent conflict in South Sudan. Riverine and coastal zones are less affected by drought in general (Figs. 2, 3 and 4), meaning that conflict is the leading trigger of food insecurity both before and after 2014 in these zones (Fig. 7)

Finally, we find that the character of food security crises associated with drought and conflict are considerably different. Drought-related food security crises were spatially widespread - often occurring at a similar spatial scale as the drought itself (Fig. 4) - and tended to last one to two years (Fig. 7, SI Fig. 10). Conflict-related food security crises were persistent, severe, and had varying spatial scales (Figs. 5, 6). The conflict-related crises in Nigeria and South Sudan were years-long, but were spatially confined in the case of Nigeria to the northeast of the country while crises were more widespread in South Sudan (Fig. 5, SI Fig. 10).

Implications of findings This study finds that how violent conflict, locusts, or drought affect food security differs by livelihood strategy, although there are responses common across livelihoods. In pastoral, agro-pastoral, and agricultural livelihoods we find drought was the primary trigger of food security crises from 2009-2013. Beginning in 2014, there was a steady increase in conflict-related food crises in all livelihood zones that caused the prevalence of food insecurity across Africa to increase. Locusts had little association with food crises in any livelihood zone, but we caution that this finding is for a period with locust swarms that do not reach the intensity of the 2019-2020 swarm.

Those engaging in pastoral livelihoods, who account for over a quarter of the population in Africa and occupy 43% of its land area[31], significantly differed in both exposure and vulnerability. Pastoralists were exposed to more variable hydroclimate conditions, exposed more frequently to locusts, and tended to be less food secure than agricultural livelihood zones. When exposed to droughts, pastoralists experienced more spatially widespread, severe, and long-lived food security crises that affect a greater fraction of the population, as compared to populations in agricultural livelihood zones.

The actions taken to address pastoralist food security during times of drought need to acknowledge the difference between agricultural and pastoral livelihood systems, as well as socioeconomic differences in access to resources. To survive droughts, herders often sell livestock to purchase food from local markets, delaying a deterioration of food security initially[32]. As a drought intensifies, the price of grain rises, animal health deteriorates, the livestock:grain terms of trade collapse, and it becomes difficult for pastoralists to meet dietary needs [32–34]. Post-drought herd reconstitution can take multiple years, and is considerably more expensive than the associated post-drought costs in agricultural zones [34–39]. These short-term responses to drought are exacerbated by long-standing social and political differences between populations practicing different livelihoods. The political exclusion of remote pastoral communities has led to a general lack of social services, physical infrastructure, and delays in government provision of food aid during food crises [40–43]. Decreasing the severity or duration of acute drought-related food crises in pastoral livelihoods, therefore, will require solutions rooted in the political, economic, and physical reality of these livelihoods where they are practiced.

One context in which our results may be useful is in improving food security early warning systems. In particular, we provide multidimensional empirical evidence of how different hazards affect the food security status of populations disaggregated by livelihood zones. Such information is applicable, for example, to improving the FEWS NET scenario development process[34], which underpins food security early warnings such as those currently being issued for East Africa at the time of writing[44]. FEWS NET food security forecasts are less accurate in pastoral as compared to agricultural livelihood zones[6], indicating an opportunity to improve future forecasts of pastoral food insecurity. To address the increasing prevalence of food security crises globally, we need to improve both our understanding of such crises and our ability to forecast them.

Methods

Data We use monthly soil moisture estimates from the Global Land Evaporation Amsterdam Model (GLEAM) v3.2a (1981-2018), which uses satellite-observed surface (0-10 cm) soil moisture, vegetation optical depth, reanalysis air temperatures, and a multisource precipitation product to derive surface soil moisture values at 0.25 degrees resolution (Martens et al., 2017). Monthly precipitation data come from the Climate Hazards group Infrared Precipitation with Stations (CHIRPS; 1981-2018) aggregated to 0.25 degrees[45]. Vegetation data come from the MODIS satellite, MOD13A1 V6 product generated every 16 days at 500-meter spatial resolution since the year 2000 [46]. We use the Enhanced Vegetation Index (EVI), which mitigates canopy background variations and maintains sensitivity in dense vegetation. The values are atmospherically corrected and masked for water, clouds, heavy aerosols, and cloud shadows. The data are temporally averaged at the monthly level using Google Earth Engine, and then spatially averaged into a 0.5 degree grid. Precipitation, soil moisture, and EVI were all averaged over the previous twelve months before standardizing values as z-scores across years. The mean and standard deviation used in the z-score for a precipitation value in April, for example, was calculated using the May-April average for all years.

Food insecurity data in this analysis is reported to be compatible with the Integrated Food Security Phase Classification (IPC) scale, which provides protocols to measure the severity of food insecurity using a five point scale: minimal food insecurity, stressed, emergency, crisis, and famine (Phases 1 through 5 respectively). The protocols and scale are designed to be applicable across countries. IPC data have become prominent in the international community, used operationally by donors, international aid agencies, and the United Nations as a means of determining food assistance needs and for formulating humanitarian response plans[47,48]. IPC data provide estimates of food security at the subnational level every three months from 2009-2016 and every four months from 2016-present for countries in West Africa, East Africa, and Southern Africa. IPC compatible data are downloaded from the FEWS NET website and converted to a regular grid of 0.1, 0.25 or 0.5 degrees.

We adopt the livelihood zones from FEWS NET as one unit of analysis. FEWS NET produces maps of livelihood zones within each country, based on geographic and climatic zones, and where people generally have similar options for obtaining food, income, and market access. These detailed maps are produced using a combination of expert and stakeholder input and Household Economic Analysis information. These livelihood zone maps are maintained by FEWS NET and are publicly available as shapefiles for geographic information systems applications (https://fews.net/sectors-topics/sectors/livelihoods). We use these shapefiles to derive simplified livelihood zones by aggregating the more detailed zones into the following classifications: coastal or riverine, pastoral, agro-pastoral, agricultural, or urban. We note that we do not analyze urban livelihood zones here due to their limited extent. For all data processed using administrative units, we use the FEWS NET administrative level 1 and 2 shapefiles.

Data on the incidence of locusts are from the FAO Locust Hub (https://locust-hub-hqfao.hub.arcgis.com/) for 2009-2018. Data are available only at annual resolution prior to 2012, so we use annual resolution data in this analysis. For IPC data reported in January and February, locust incidence from the previous year is used, for those data reported in April, June, or July the average of the current year and the previous year is used, and for IPC data reported in October the current year is used. We count incidence of events in which locusts were detected, 'LOCPRESENT'=1 in the data, in each administrative unit level 1 per year.

For information on conflict in Africa we use The Armed Conflict Location and Event Data (ACLED)[49]. We use metrics of deaths or frequency of events occurring in the previous twelve months within a given administrative level 1 unit for all events in the battles, explosions/remote violence, riots, or violence against civilians event categories. We choose administrative units because violent conflict in a location is likely to have knock-on effects that influence food access[21] by affecting institutions or infrastructure. We tested the sensitivity of the analysis to the area of aggregation, using the intersection of administrative unit 2 and livelihood zones and found the results to be similar. Similar to hydroclimate and vegetation variables, we sum deaths from conflict or frequency of conflict events over the preceding twelve months at each time step.

Food prices are from the FAO's GIEWS Food Prices Monitoring and Analysis (FPMA), which tracks monthly wholesale and retail prices at the crop and city-market level. We use standardized USD-equivalent crop prices for maize, rice, wheat, cassava/gari, millet, and sorghum. Missing monthly prices are linearly interpolated, and prices are normalized to the 2015 average. A country-level staple index is weighted by FAO country-level caloric dependence according to FAO Food Balance Sheets averaged over the 2000-2013 period for each crop and the crop's caloric content (NutVal 4.1). The 2000-2013 time period was used to calculate average caloric dependency ratios due to data availability. Note that because price data are not available for all staple crops in every country, each country's index consists of the crops available in its city-markets.

We use the WorldPop database for annual, gridded population data (https://www.worldpop.org/). WorldPop disaggregates census-level data to a regular grid using statistical models that incorporate survey, satellite, and cell-phone data[50]. Using a modeling approach to disaggregate data avoids the problem of overestimating population in sparsely populated rural areas[51]. WorldPop data is aggregated up to 0.1 degree grid to match the IPC data.

We derive conservative estimates of the crude death rate (CDR) related to food insecurity following Maxwell et al. (2020) by combining information from the IPC data with population data. Each IPC phase includes thresholds for indicators of food consumption, changes in livelihoods, acute malnutrition prevalence, and crude death rate, measured as the number of people dying per day per 10,000 people. The most conservative estimate of mortality associated with each IPC phase[47] is multiplied by the population in that phase to derive a conservative estimate of crude death rate. This estimate of crude death rate is likely conservative and may not accurately represent actual mortality during events for this reason, but is useful as a means of comparing death rates across time and between events[9]. For example, IPC phase 3 is associated with a CDR range of 0.5-1 person/10,000 people/day, so the lower threshold of 0.5 is used. For IPC phases 4 and 5, the lower thresholds of 1 person/10,000/day and 2 people/10,000/day are used, respectively.

We define the analysis units used in the exposure and vulnerability analyses as the unique combination of livelihood zones and administrative level 2 units, which we create in ArcGIS by intersecting the two shapefiles and which will be referred to as analysis units hereafter. We use the FEWS NET administrative boundaries and livelihood zone boundaries to define these boundaries. We calculate the average precipitation, soil moisture, or EVI anomaly at each time step within each analysis unit. We link the analysis unit to the appropriate administrative level 1 unit, as well as the associated conflict and locust exposures. FEWS NET IPC compatible data on food security are reported at the livelihood zone or administrative unit, although there are considerable differences between the spatial resolution of reporting between countries. We chose the combination of administrative level 2 and livelihood zone as a compromise between the finest-scale data available in Ethiopia, for example, where data are reported at the Woreda level (administrative level 3), and more coarse reporting units such as Somalia, where food security data are reported by livelihood zone.

Methods Food security crises are dynamic phenomena with dimensions of magnitude, severity, spatial coverage, and duration[9]. Even after the famine declaration many of the deaths occurred outside of the areas declared to be in famine. Consider, for example, the famine in the Unity state of South Sudan; in 2017 famine conditions disappeared from the state but the number of people affected by food insecurity increased (e.g. the severity of the crisis decreased while the magnitude increased)[9]. Consider also the 2010-2012 food security crisis in Somalia, in which the majority of the excess mortality occurred either before famine conditions were declared or outside of the famine affected regions, highlighting the importance of understanding spatial coverage and duration of a crisis in addition to severity. Studying only the factors that affected the maximum severity of food insecurity in either of these examples provides at best an incomplete understanding of the crisis. In our analysis we characterize not only the severity of food security crises by livelihood, but also the spatial coverage, magnitude, and duration.

To analyze the exposure of each livelihood zone to the hazards of drought, conflict, and locusts, we aggregate each variable over the analysis units, which are the unique combination of livelihood zones and administrative level 2 units. We calculate the soil moisture anomaly over the previous year, frequency of conflict over the previous year, frequency of adult locusts over the previous year, and mode IPC value for each analysis unit at each time step. We next convert soil moisture values into measures of the coefficient of variation by dividing the standard deviation by the mean soil moisture value at the analysis unit level. We plot the distribution of each variable as a function of livelihood zone associated with the analysis unit in Figure 2. Note that the soil moisture coefficients of variation are evaluated over the whole time period to provide one value per location and the distributions shown in Figure 2 are over these values. In contrast, the IPC level is for a given month and year, as are the conflict frequency and frequency of locusts during the year prior. The distributions of IPC level, locusts, and conflict in Figure 2 are therefore across space and time.

To analyze the relation between the severity of food insecurity - as measured by the IPC phase - and drought, conflict, or locusts, we plot distributions of each variable at the spatial scale of the analysis unit disaggregated by livelihood zone and IPC level (see Figure 3). The soil moisture distributions here are not the coefficients of variation as in Figure 2, but instead the standardized z-scores of soil moisture over the year prior to the IPC observation. The frequency of locusts and conflict are likewise aggregated over the year prior to the IPC observation, although note that the time resolution of the locusts data makes the time dimension inexact (see Data section).

To analyze the evolution of food security status during droughts, we use an event composite analysis. We first identify all drought-related food security crises by selecting each month in which the IPC scale indicated emergency, crisis, or famine conditions present in a country that occurred concurrently with deficit precipitation over the previous year. Because we are interested in the multi-year evolution of these events, we identify the onset of the food insecurity and drought - again, as measured using precipitation over the previous year - as the starting month and 24 months later as the end month. The start of events often coincided with the onset of the hunger season in which there were inadequate seasonal rains. We do not allow for overlapping events as this would double-count events in the composite. In the event of consecutive years of drought food security crises, we choose the second year of the multi-year event. We use the national scale as the spatial scale for events because the food security outcomes related to a drought depends on the economic and political response of social and political institutions.

There may be multiple food insecurity events, therefore, relating to a single mesoscale drought. There are three events, for example, that relate to the 2011 failure of the long rains in the Horn of Africa because the drought affected Ethiopia, Somalia, and Kenya[26]. Using this procedure, we identify thirty-two drought-related food security events. By averaging all drought-related food security crises from each country together, we isolate the influence of drought on food security while treating the effects of conflict as a random variable that averages out. This approach is supported by the lack of any discernible relationship between drought and conflict in the drought composite.

To attribute changes in food security status to drought and conflict, we conducted a maximum covariance analysis (MCA). MCA is a methodology that identifies the patterns in two space-time datasets that explain the maximum covariance between them. Here we work with matrices that describe food security in space and time, F, and matrices that describe the hazards, H, that drive food insecurity. To construct F and H we first resample the soil moisture, precipitation, crude death rate, and IPC data to a 0.5 degree grid to match the EVI and conflict data resolution. We then construct the N x M food security indicator matrix, F, where N is the number of observations in space and M the number of time steps, which are every 3-4 months (see Data), by concatenating observations from gridded IPC data with observations from gridded estimates of the crude death rate. Next, we similarly constructed the N x M hazard matrix, H, where N is the number of observations in space and M the number of time steps, by concatenating precipitation anomalies, soil moisture anomalies, EVI anomalies, estimates of conflict frequency, and estimates of deaths from conflict. Conflict and crude death rate data were log-transformed then de-meaned, food security indicators were de-meaned, and climate data was standardized prior to calculating the cross covariance matrix used in the maximum covariance analysis. We conducted the analysis separately for each country by masking out all areas outside of the given country. We chose the country-scale because while the incidence of violent conflict and drought crosses borders, the infrastructure, institutions, and policies that determine food security outcomes will depend on individual countries, which makes the country scale a natural domain for the analysis. After conducting the analysis for each country, we retained only the leading modes that were well separated from other modes based on their eigenvalues (not shown). We determine the spatial patterns of covariance between food security and hazard viz:

$$FH^T = U\Sigma V^T$$

Where FH^T is the cross covariance matrix. The orthonormal matrices U and V then contain the spatial singular value decomposition modes corresponding to the data fields F and H, respectively. Σ is a matrix with the singular values on the diagonal. The leading modes represent the primary patterns of covariance between the two fields. We next recover the time-expansion coefficients for each mode, k, as

$$A_k = U_k^T F$$
$$B_k = V_k^T H$$

such that we can reconstruct the portion of the total variance in the data related to each singular value decomposition mode as

$$F_k = A_k U_k$$
$$H_k = B_k V_k$$

The maximum covariance analysis provides a series of spatial patterns (U and V) of the stresses to which food systems are subject (variations in precipitation, soil moisture, vegetative stress, conflict frequency, and conflict intensity - contained within V) and the associated spatial pattern of the response of food security indicators (variations in the IPC level or associated crude death rate - contained within U). A spatial pattern of widespread drought and vegetative stress, for example, coincides with degraded food security in the same region in the second MCA mode calculated for Ethiopia (SI Figure 4)

The eigenvalues of the MCA indicate the covariance between the hazard variable matrix, H, and the food security variables matrix, F, explained by each mode. The extent to which each mode explains the variance of the individual variables within each matrix can be calculated by comparing the variance of the reconstruction using each mode to the total variance of the field (e.g. by comparing the field reconstructed from mode k, F_k, to the total variance of the original field F).

The separable, leading modes are categorized as drought-related or conflict-related modes based on pattern loadings, time expansion coefficients, and variance explained in the conflict co-variates (conflict-related deaths and frequency of conflict) or the physical climate variables (precipitation, soil moisture, and EVI). Before attributing any mode to being related to either physical variables or conflict, we reference external literature to cross-check the associations in the maximum covariance analysis. Below is our attribution for each mode used in Figure 6.

In Ethiopia the first two modes were well separated from the remaining modes, with both modes loading heavily on physical variables and less strongly on conflict-related variables (SI Fig. 4, 5). The first mode describes increased precipitation, wet soils, little vegetative stress, and relatively food secure conditions in the Somali region of Ethiopia. The second mode describes widespread drought and vegetative stress in the northwest of Ethiopia, which coincides with food insecure conditions in the same regions. Both of these first two modes were labeled to be primarily physical climate-related modes. That recent food security crises in Ethiopia are predominantly attributable to drought is supported by the interview-based analysis of Maxwell and Hailey (2020), which found the 2011 food security crisis to be drought driven and the 2015-2018 crisis to be largely attributable to drought, although they note that localized conflict may be a contributing factor in the latter case. Drought, in fact, affected food security in some portion of Ethiopia nearly every year between 2009 and 2018, including major events in 2009, 2011, 2015, and 2017[10,26,27]

In Somalia we retain only the first mode, which loads on both conflict-related variables and on physical climate-related variables (Fig. 6). This mode loads primarily on the confirmed 2011 famine and the averted 2017 famine, which Maxwell and Hailey (2020) attribute to both drought and conflict. Maxwell and Majid (2016) outline the ways that violent conflict delayed the government and humanitarian response to the drought in 2011, which allowed food security to deteriorate considerably before intervention. This mode is further discussed in the main text.

In Kenya the first mode is retained and corresponds to wet growing conditions, with little vegetative stress that corresponds to food secure conditions throughout the country (SI Fig. 7). This mode was labeled as a physical climate mode. Maxwell and Hailey (2020) confirm that recent food insecurity in Kenya was mostly affected by drought.

In Nigeria we retain only the first mode, which describes a deterioration of food security in the northeast coincident with significant increases in the frequency of conflict related (Fig. 5; SI Fig 7). While this mode loads also on insignificant trends towards dry conditions in Nigeria, the relatively drier conditions do not correspond in space to significant changes in food security status, while the spatial loadings on conflict-related variables and changes in food security status occurred simultaneously in the northeast. This mode describes the rise of Boko-Haram related violence centered in the northeast state of Borno in Nigeria that has disrupted livelihoods, displaced people, and reduced households' ability to access food, which led to persistent food insecurity including a possible, but unconfirmed, famine[12–14]. We furthermore see a sharp increase in food price inflation in Nigeria in 2016 (SI Fig 3) related to conflict and oil pipeline sabotage in the Niger Delta, which reduced national oil production by over 50%[28]. Reduced government revenue, already low due to the drop in global oil price, contributed to a recession in 2016 and a major currency devaluation, which produced high domestic inflation

In Sudan and South Sudan, we retain two modes of variability, which are both separable from the remaining modes. The first mode describes wet conditions coincident with little vegetative stress, but an increased frequency of conflict across the domain that coincides with higher rates of food insecurity. This mode describes the statistically significant increase in conflict and decrease in food security over the domain (Fig. 5, SI Fig. 8, 9). We therefore attribute this mode to be primarily conflict-related. The second mode describes widespread precipitation deficits, dry soils, and vegetation stress, with soil moisture drought particularly severe in South Sudan. This mode loads heavily on the droughts of 2010 and 2017, which, in combination with conflict during 2017-2019, led to food insecurity in the region[9, 20, 29]. The conflict in South Sudan affected food security directly, but also reduced economic activity by disrupting oil production[30](SI Fig. 3).

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1. FEWSNET. Drivers of acute food insecurity in 2020. Tech. Rep., Famine Early Warning System Network (2020).

2. FAO, U. W. W., IFAD. The state of food security and nutrition in the world 2019: safeguarding against economic slowdowns and downturns (2019).

3. Salih, A. A., Baraibar, M., Mwangi, K. K. & Artan, G. Climate change and locust outbreak in east africa. *Nature Climate Change* **10**, 584–585 (2020).

4. FAO. Impact of desert locust infestation on household livelihoods and food security in ethiopia. Tech. Rep., Food and Agriculture Organization (2020).

5. Maxwell, D. & Hailey, P. The politics of information and analysis in famines and extreme emergencies synthesis of findings from six case studies. Tech. Rep., Feinstein International Center (2020).

6. Krishnamurthy, P. K., Choularton, R. J. & Kareiva, P. Dealing with uncertainty in famine predictions: How complex events affect food security early warning skill in the greater horn of africa. *Global Food Security* **26**, 100374 (2020).

7. Majid, N. & McDowell, S. Hidden dimensions of the somalia famine. *Global Food Security* **1**, 36–42 (2012).

8. Maxwell, D., Majid, N., Adan, G., Abdirahman, K. & Kim, J. J. Facing famine: Somali experiences in the famine of 2011. *Food policy* **65**, 63–73 (2016).

9. Maxwell, D., Khalif, A., Hailey, P. & Checchi, F. Determining famine: Multi-dimensional analysis for the twenty-first century. *Food Policy* 101832 (2020).

10. Mohamed, A. A. Food security situation in ethiopia: a review study. *International Journal of Health Economics and Policy* **2**, 86–96 (2017).

11. Devereux, S. & Sussex, I. *Food insecurity in Ethiopia* (Institute for Development Studies, 2000).

12. Ayinde, I. A., Otekunrin, O. A., Akinbode, S. O. & Otekunrin, O. A. Food security in nigeria: Impetus for growth and development. *Journal of Agricultural Economics* **6**, 800–813 (2020).

13. Otekunrin, O. A., Otekunrin, O. A., Momoh, S. & Ayinde, I. A. How far has africa gone in achieving the zero hunger target? evidence from nigeria. *Global Food Security* **22**, 1–12 (2019).

14. Azad, M., Crawford, E. E. & Kaila, H. K. Conflict and violence in nigeria: Results from the north east, north central, and south south zones. Tech. Rep., The World Bank (2018).

15. Young, H., Jaspers, S., Brown, R., Frize, J. & Khogali, H. *Food-security assessments in emergencies: a livelihoods approach* (Overseas Development Institute, 2001).

16. de Perez, E. C. *et al.* From rain to famine: assessing the utility of rainfall observations and seasonal forecasts to anticipate food insecurity in east africa. *Food security* **11**, 57–68 (2019).

17. Verpoorten, M. Household coping in war-and peacetime: Cattle sales in rwanda, 1991–2001. *Journal of development Economics* **88**, 67–86 (2009).

18. Helman, D. & Zaitchik, B. F. Temperature anomalies affect violent conflicts in african and middle eastern warm regions. *Global Environmental Change* **63**, 102118 (2020).

19. Von Uexkull, N. Sustained drought, vulnerability and civil conflict in sub-saharan africa. *Political Geography* **43**, 16–26 (2014).

20. Brück, T. & d'Errico, M. Food security and violent conflict: Introduction to the special issue. *World development* **117**, 167–171 (2019).

21. Martin-Shields, C. P. & Stojetz, W. Food security and conflict: Empirical challenges and future opportunities for research and policy making on food security and conflict. *World Development* **119**, 150–164 (2019).

22. Justino, P. Nutrition, governance and violence: A framework for the analysis of resilience and vulnerability to food insecurity in contexts of violent conflict (2012).

23. Arias, M. A., Ibáñez, A. M. & Zambrano, A. Agricultural production amid conflict: Separating the effects of conflict into shocks and uncertainty. *World Development* **119**, 165–184 (2019).

24. Group, W. B. Federal republic of somalia systematic country diagnostic (2018).

25. Maxwell, D. G. *Famine in Somalia* (Oxford University Press, 2016).

26. Anderson, W. *et al.* Towards an integrated soil moisture drought monitor for east africa. *Hydrology and Earth System Science* **16**, 2893–2913 (2012).

27. Funk, C. *et al.* Examining the role of unusually warm indo-pacific sea-surface temperatures in recent african droughts. *Quarterly Journal of the Royal Meteorological Society* **144**, 360–383 (2018).

28. Update 1-sabotage on nigeria's oil-exporting nctl pipeline causes significant production losses. Tech. Rep., Reuters (2019).

29. FEWSNET. Trends in acute food insecurity, 2013-2018. South Sudan Special Report, Famine Early Warning System Network, https://fews.net/east-africa/south-sudan/special-report/december-2018 (2018).

30. Dihel, N. C. & Pape, U. J. South sudan-economic update: taming the tides of high inflation-policy options. Tech. Rep., The World Bank (2017).

31. Osman, A., Olesambu, E. & Balfroid, C. Pastoralism in africa's drylands: Reducing risks, addressing vulnerability and enhancing resilience. Tech. Rep., Food and Agriculture Organization (2018).

32. Hein, L., Metzger, M. J. & Leemans, R. The local impacts of climate change in the ferlo, western sahel. *Climatic change* **93**, 465 (2009).

33. Devereux, S. Why does famine persist in africa? *Food security* **1**, 25 (2009).

34. FEWSNET. Integrating livestock herd dynamics into scenario development. Guidance document 6, Famine Early Warning System Network (2018).

35. Hesse, C. & Cotula, L. Climate change and pastoralists: Investing in people to respond to adversity. *Sustainable Development Opinion Papers. London: IIED* (2006).

36. Toulmin, C. Livestock losses and post-drought rehabilitation in sub-saharan africa (1985).

37. Lesnoff, M., Corniaux, C. & Hiernaux, P. Sensitivity analysis of the recovery dynamics of a cattle population following drought in the sahel region. *Ecological modelling* **232**, 28–39 (2012).

38. White, C. Herd reconstitution: the role of credit among wodaabe herders in central niger. *Cambridge Anthropology* 30–42 (1984).

39. Ahmed, A. G. M., Azeze, A., Babiker, M. & Tsegaye, D. Post drought recovery strategies among the pastoral households in the horn of africa: A review (2002).

40. Coast, E. Maasai socioeconomic conditions: a cross-border comparison. *Human ecology* **30**, 79–105 (2002).

41. Raleigh, C. Political marginalization, climate change, and conflict in african sahel states. *International studies review* **12**, 69–86 (2010).

42. Smith, K., Barrett, C. B. & Box, P. W. Participatory risk mapping for targeting research and assistance: with an example from east african pastoralists. *World Development* **28**, 1945–1959 (2000).

43. Keen, D. *et al. The benefits of famine: a political economy of famine and relief in Southwestern Sudan 1983-89.* (James Currey Ltd, 2008).

44. Funk, C. Ethiopia, somalia and kenya face devastating drought. *Nature* (2020).

45. Funk, C. *et al.* The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific data* **2**, 1–21 (2015).

46. Didan, K. Mod13q1 modis/terra vegetation indices 16-day l3 global 250m sin grid v006. *NASA EOSDIS Land Processes DAAC* **10** (2015).

47. Young, H. & Jaspars, S. Review of nutrition and mortality indicators for the integrated food security phase classification (ipc): Reference levels and decision-making. *Inter-Agency Standing Committee Nutrition Cluster and ECHO* (2009).

48. Partners, I. G. *Integrated Food Security Phase Classification: Technical Manual Version 2.0: Evidence and Standards for Better Food Security Decisions* (Food and Agriculture Organization of the United Nations, 2012).

49. Raleigh, C., Linke, A., Hegre, H. & Karlsen, J. Introducing acled: an armed conflict location and event dataset: special data feature. *Journal of peace research* **47**, 651–660 (2010).

50. Tatem, A. J. Worldpop, open data for spatial demography. *Scientific data* **4**, 1–4 (2017).

51. Leyk, S. *et al.* The spatial allocation of population: A review of large-scale gridded population data products and their fitness for use. *Earth System Science Data* **11** (2019).

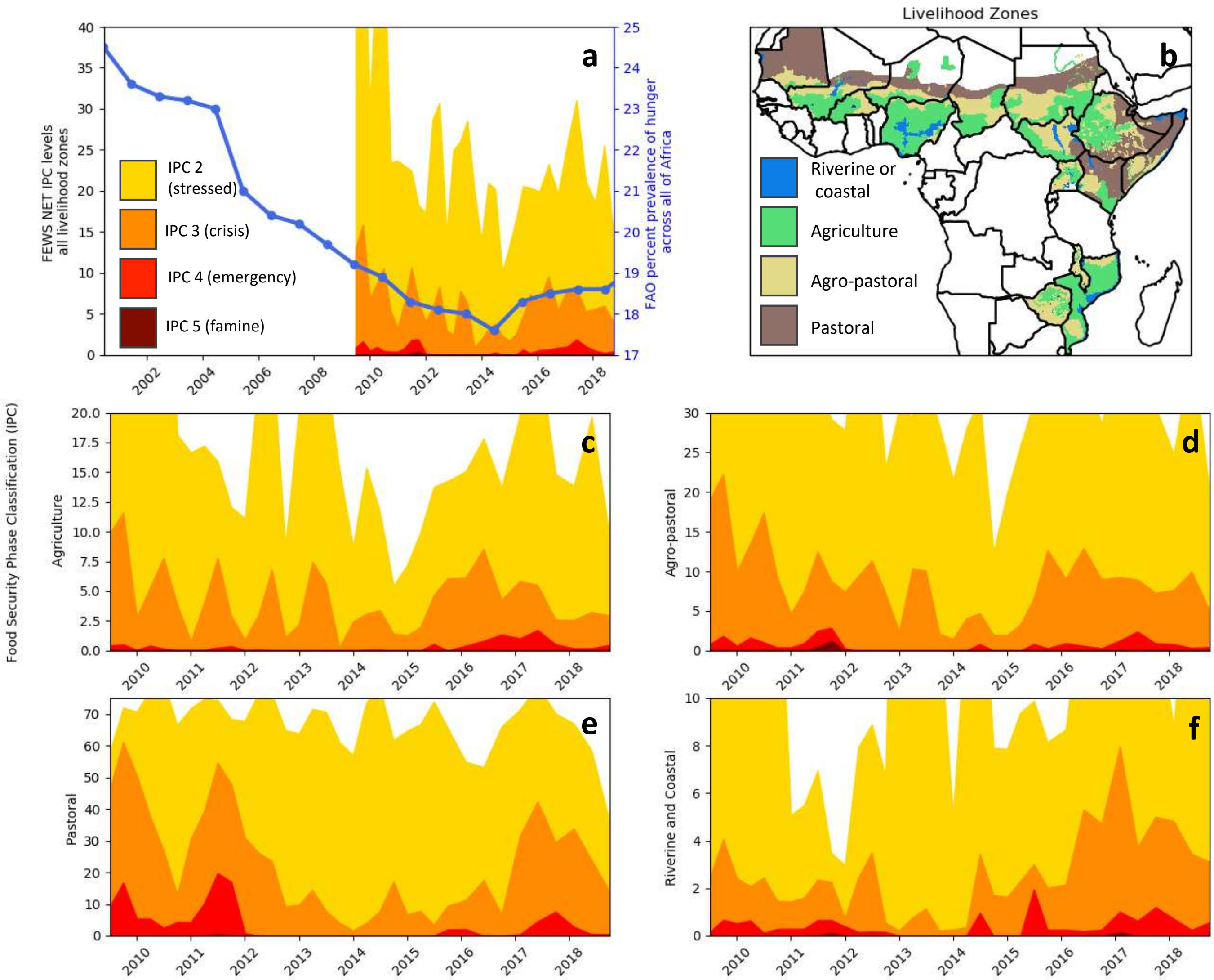


Figure 1: **Percent of the population in each Integrated Phase Classification (IPC) level** across all livelihood zones (panel a, shading) in countries included in the analysis, prevalence of hunger across all of Africa (panel a, blue line). Livelihood zones (panel b) in the countries included in this analysis, uncolored areas are excluded from further analysis. Percent of the population in each IPC level in agricultural (c), agro-pastoral (d), pastoral (e), and riverine or coastal (f) livelihoods. Note the differing y-axes in panels c-f.

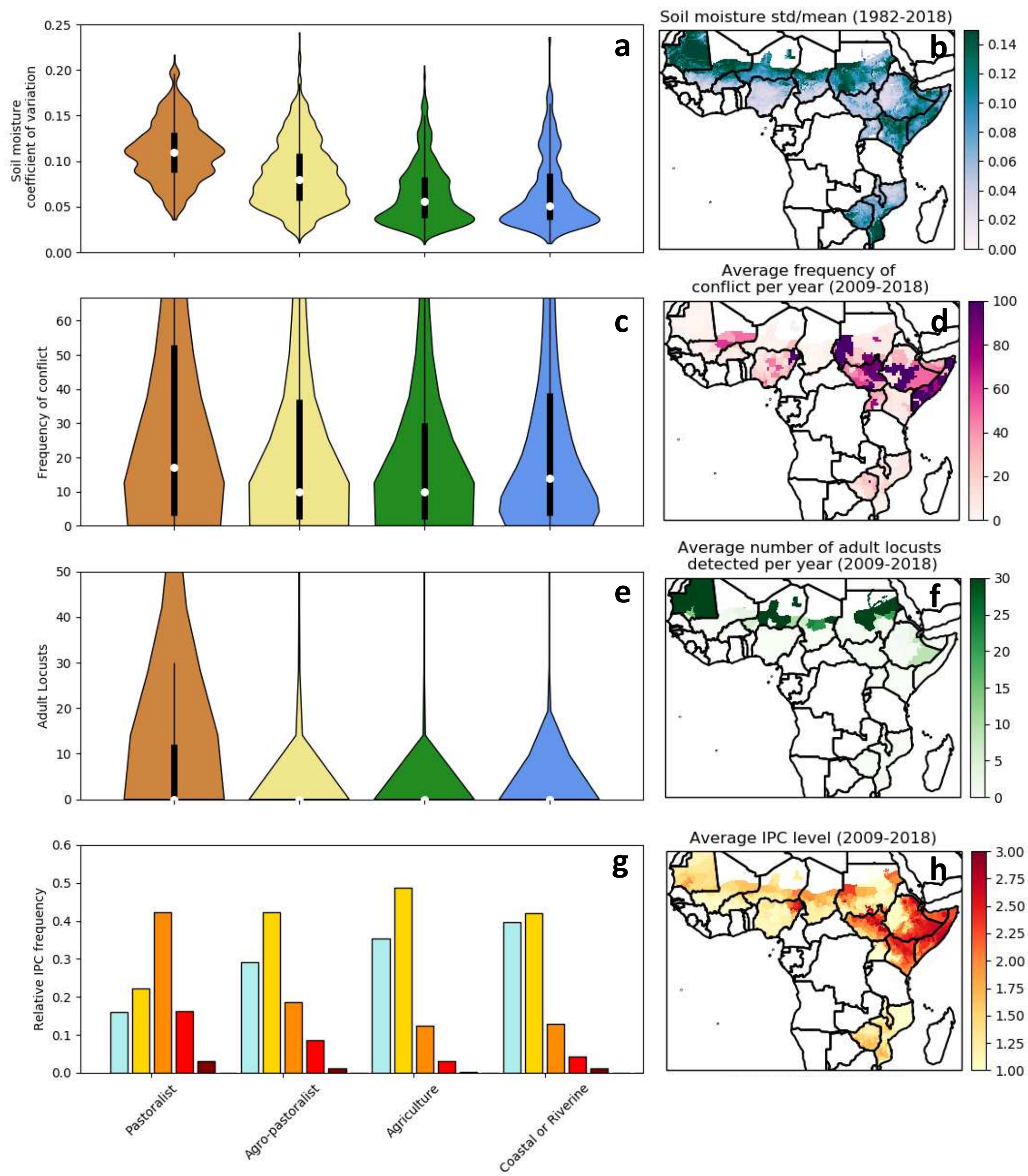
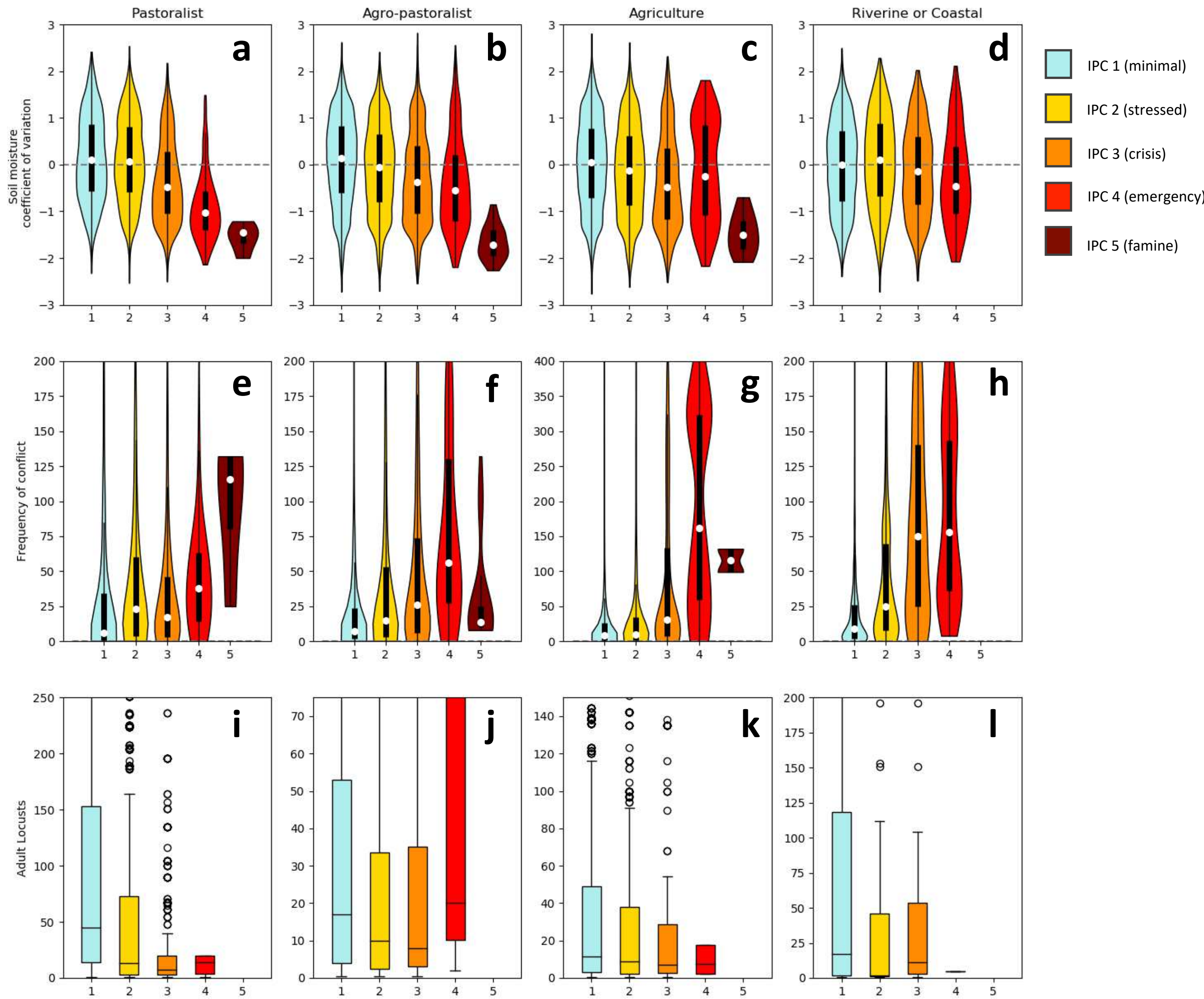


Figure 2: **Exposure to drought, locusts, and conflict, by livelihood zone**. Violin plots (shaded) depict probability density functions of each variable, which are also depicted using the inset box-plots showing the interquartile spread in black and median in white. Soil moisture coefficient of variation (a,b), frequency of conflict (c,d), incidence of locusts (e,f), and IPC level (g,h) distributions across livelihood zones and plotted spatially, respectively. Colored bars in panel (g) correspond to IPC 1 (minimal stress; light blue), IPC 2 (stressed; yellow), IPC 3 (crisis, orange), IPC 4 (emergency; red), IPC 5 (crisis; maroon).



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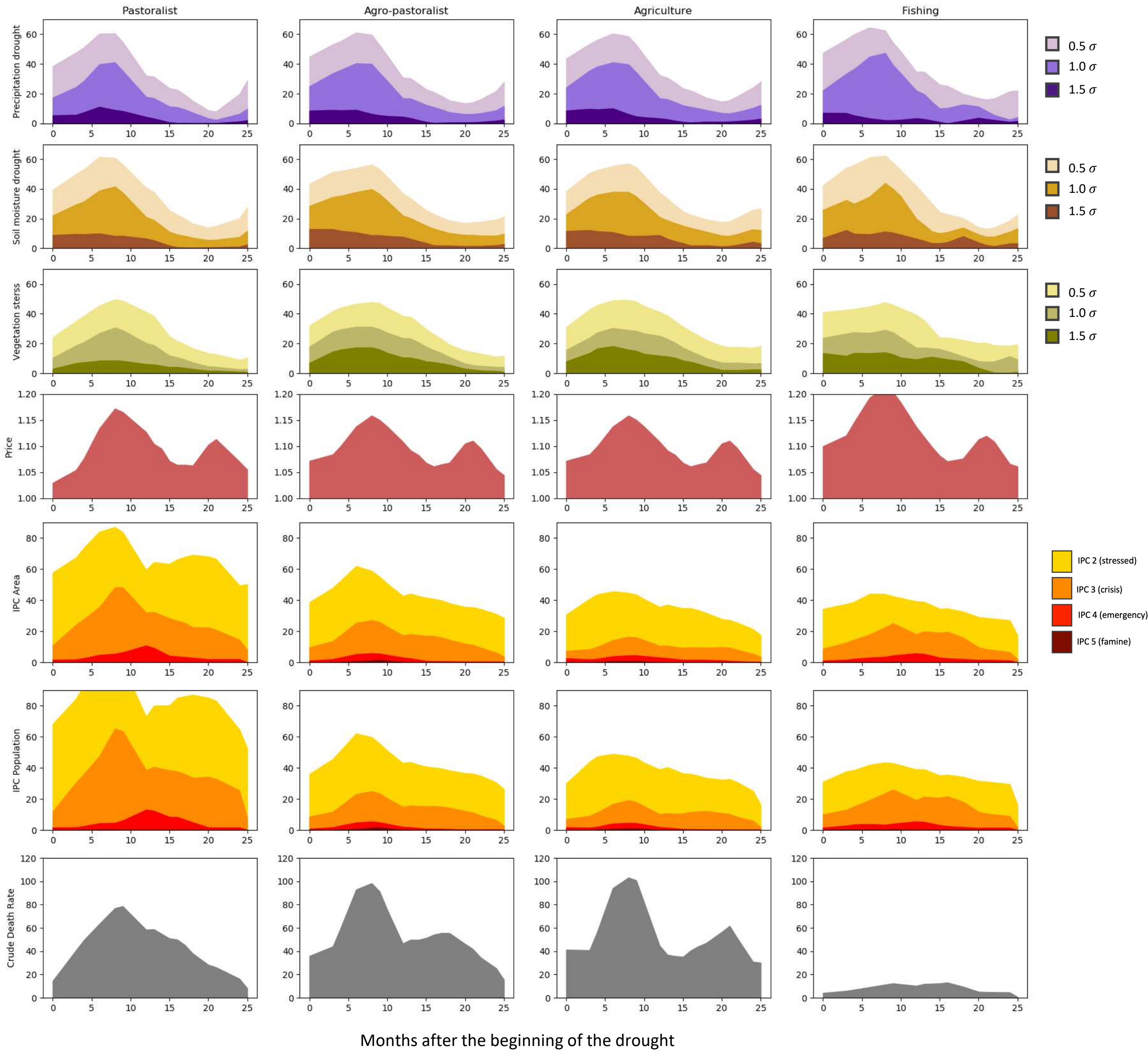

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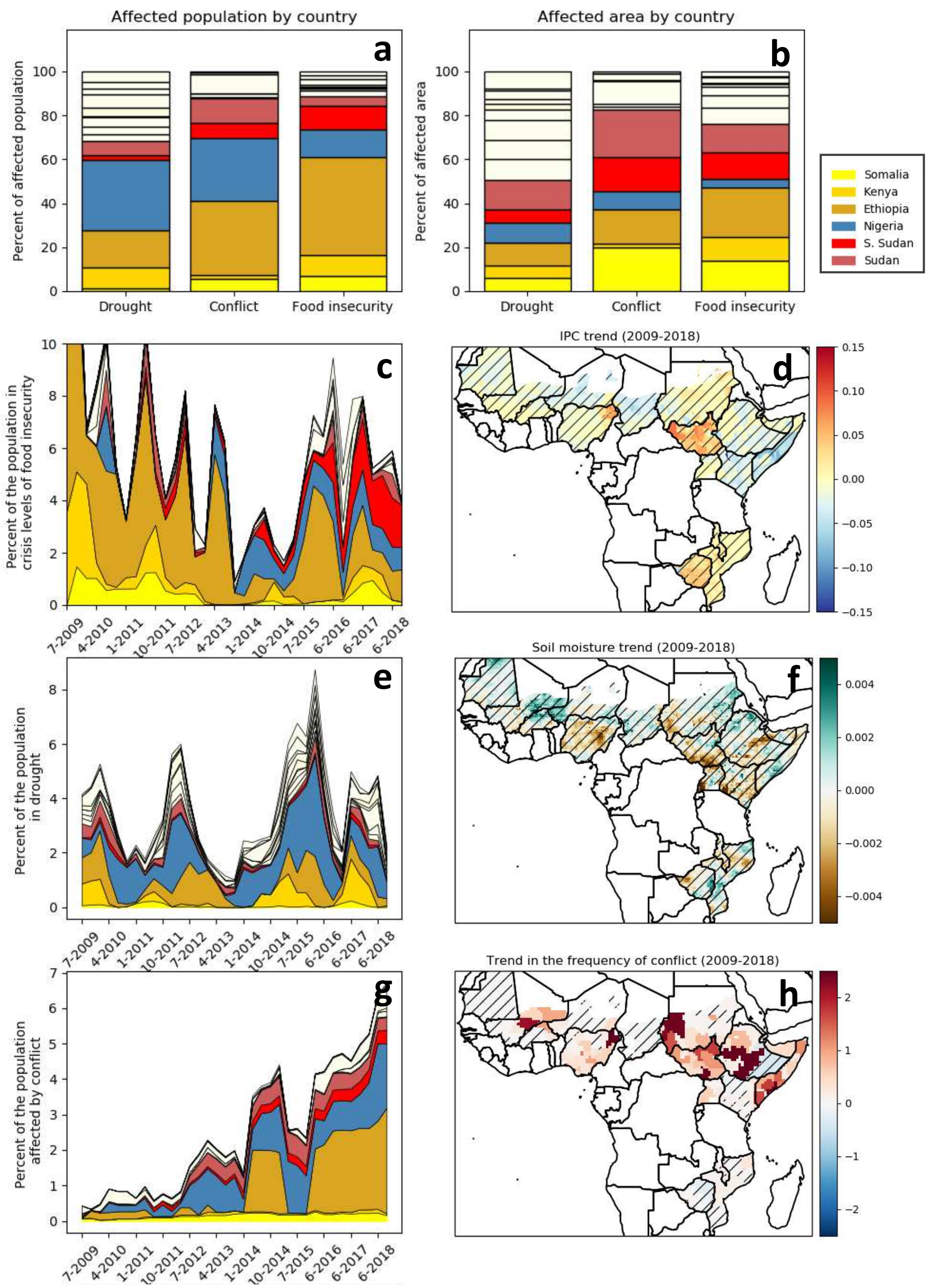


Figure 5: **Distribution of hazards and trends in hazards by country**. The prevalence of drought, conflict, and food crises (IPC $\geq$ 3) in each country as measured as a percent of total affected population (a) or area (b) over the entire study period. Six of the fourteen countries are color coded as indicated in the legend in panels a-c, e and g. Variations in time of the percent of the total population across all study countries in food crisis, soil moisture drought, and exposed to conflict (c, e, g) and the spatial distribution of the trend over 2009-2018 of the IPC level, soil moisture anomaly, and frequency of conflict in study countries (d, f, h), with insignificant (p$\geq$0.05) trends hatched.

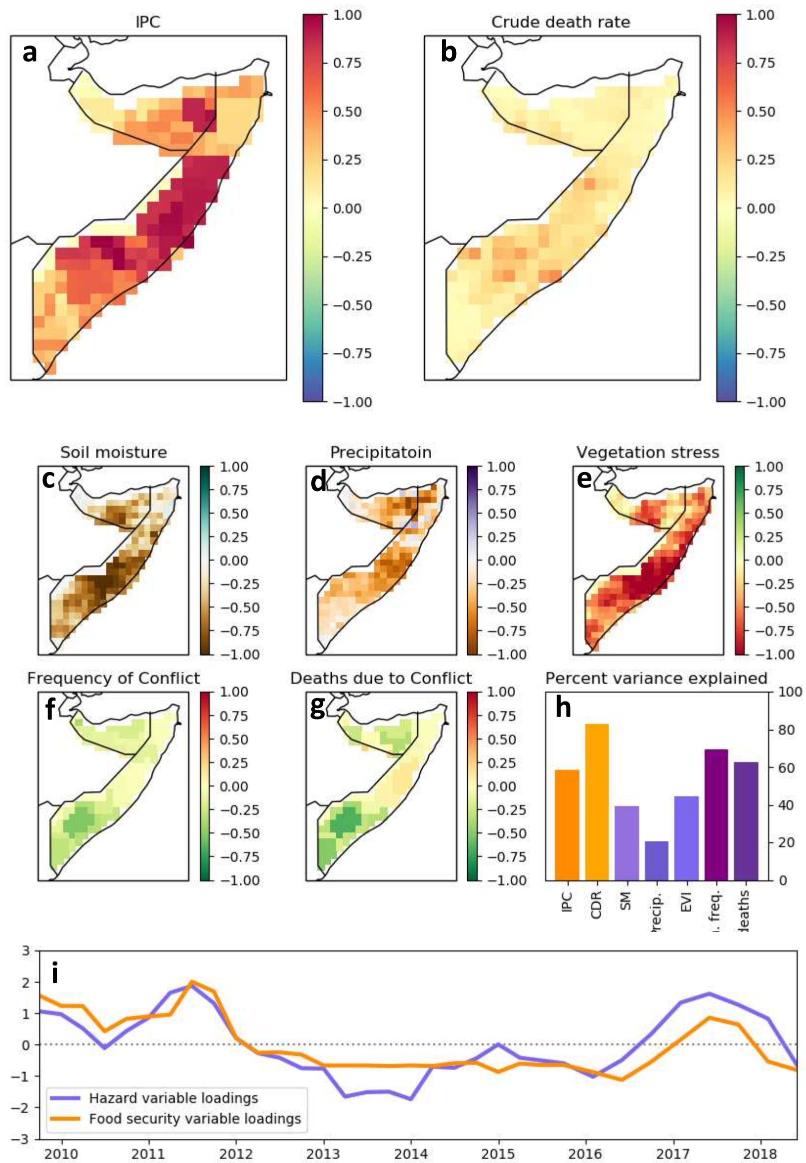


Figure 6: **Maximum covariance analysis mode 1 for Somalia**, which explains 46% of the covariance between food security variables and hazard variables. Spatial loading pattern of the first mode on food security variables (a,b) and hazard variables (c-g). Variance explained by mode 1 for each variable (h). Time expansion coefficients for the first mode (i). All units are standardized spatial loadings and time-expansion coefficients. See Methods section for details. Somalia mode 1 is a mixed conflict and drought mode based on the spatial loading patterns and variance explained for each variable.

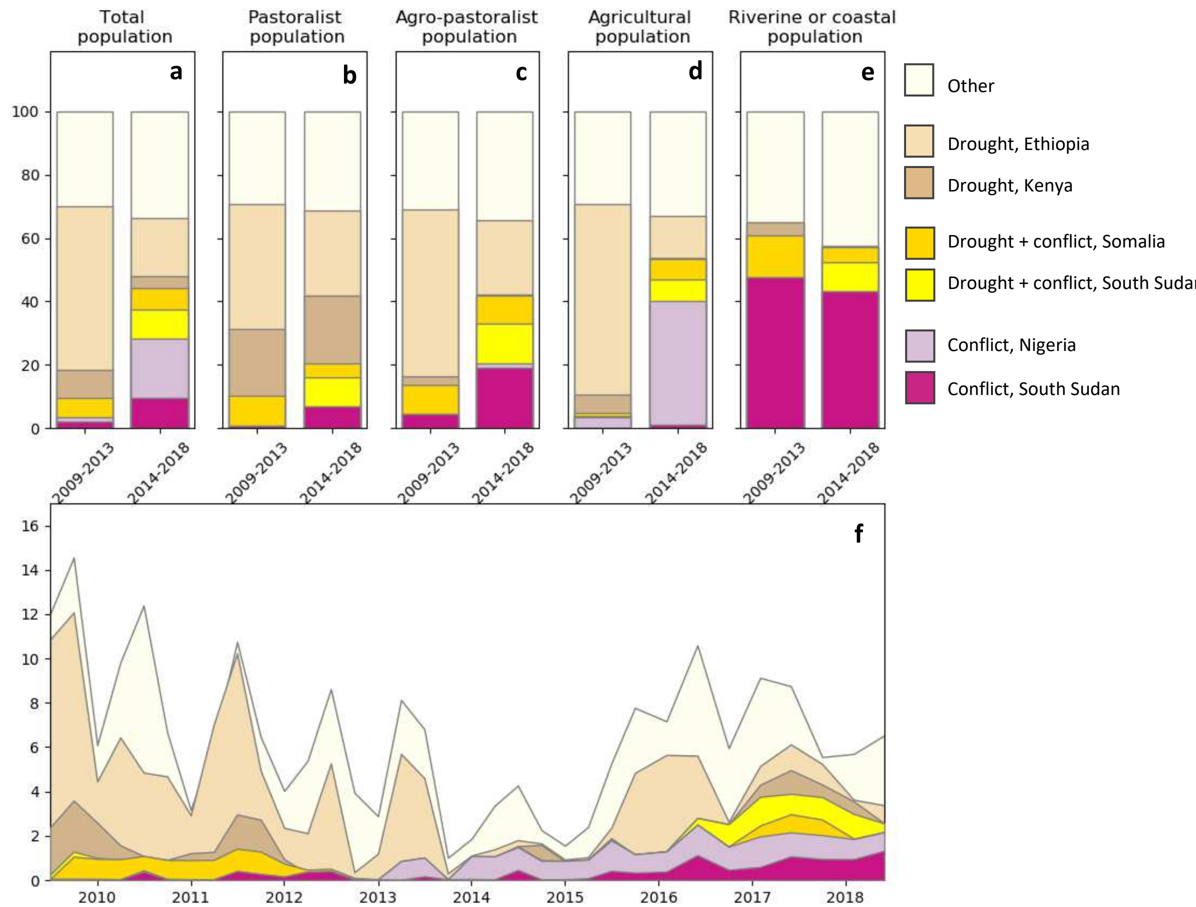
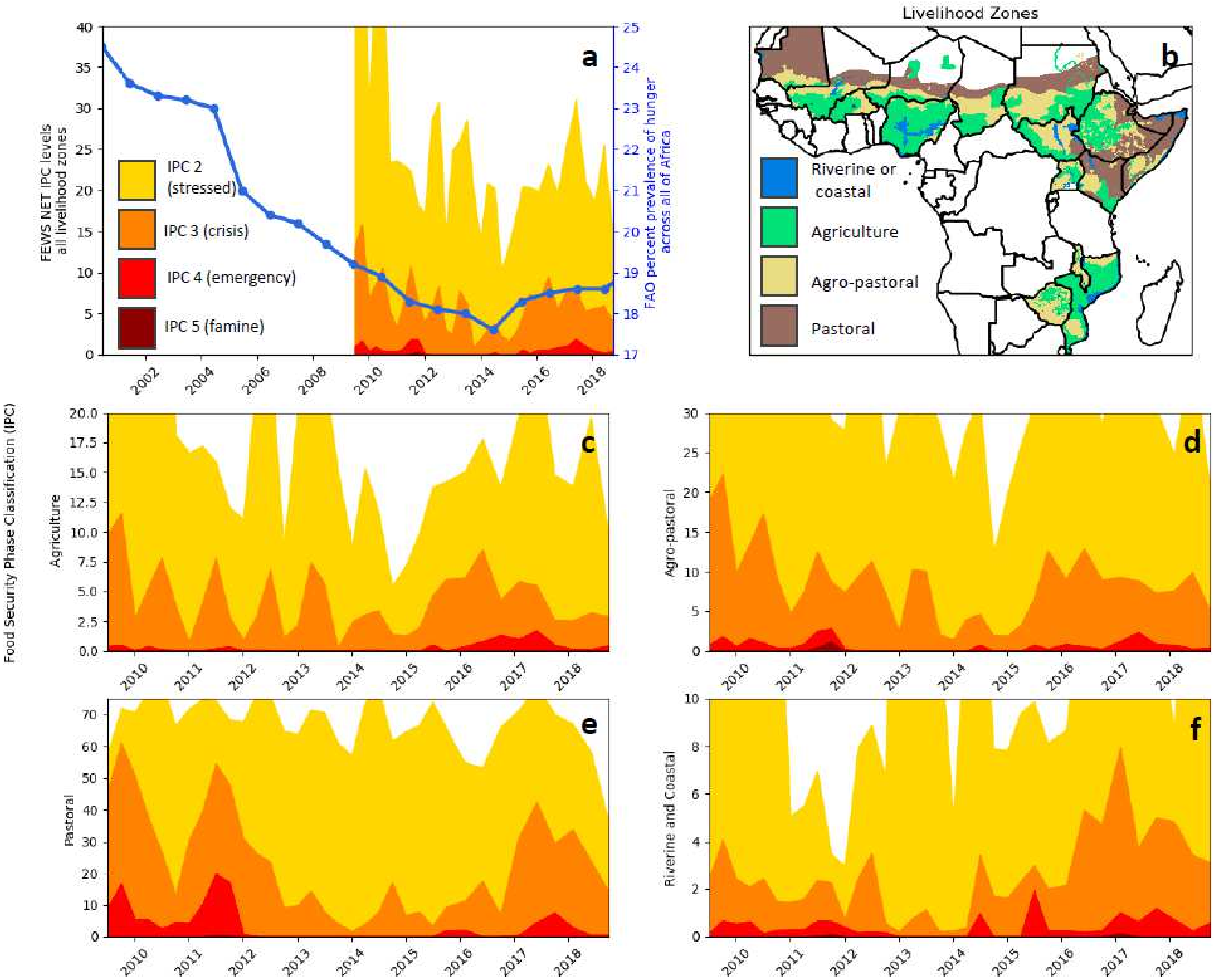


Figure 7: **Attribution of the primary trigger of food insecurity** for populations in crisis (IPC $\geq$ 3; see text for discussion of triggers). 'Other' indicates populations in food crisis not covered by the leading modes of the MCA analysis in Ethiopia, Kenya, Somalia, Nigeria, or South Sudan. Percent of the population of all fourteen study countries in IPC $\geq$ 3 attributed to each trigger (a-e) in total and in each livelihood zone from 2009-2013 (left bars) and from 2014-2018 (right bars). Population in IPC $\geq$ 3 (crisis) level as a percent of total population in study countries over time (f)

Figures



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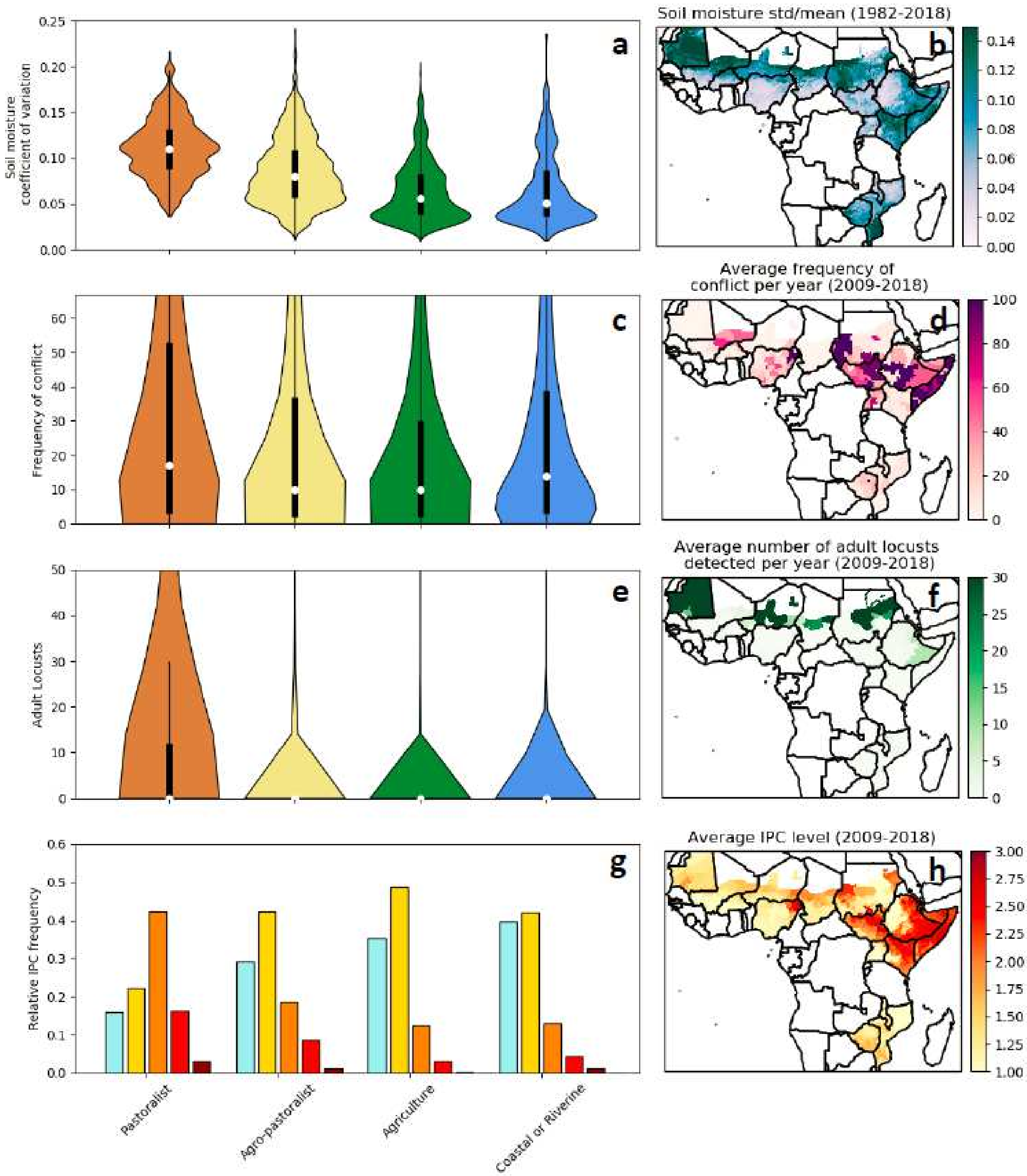

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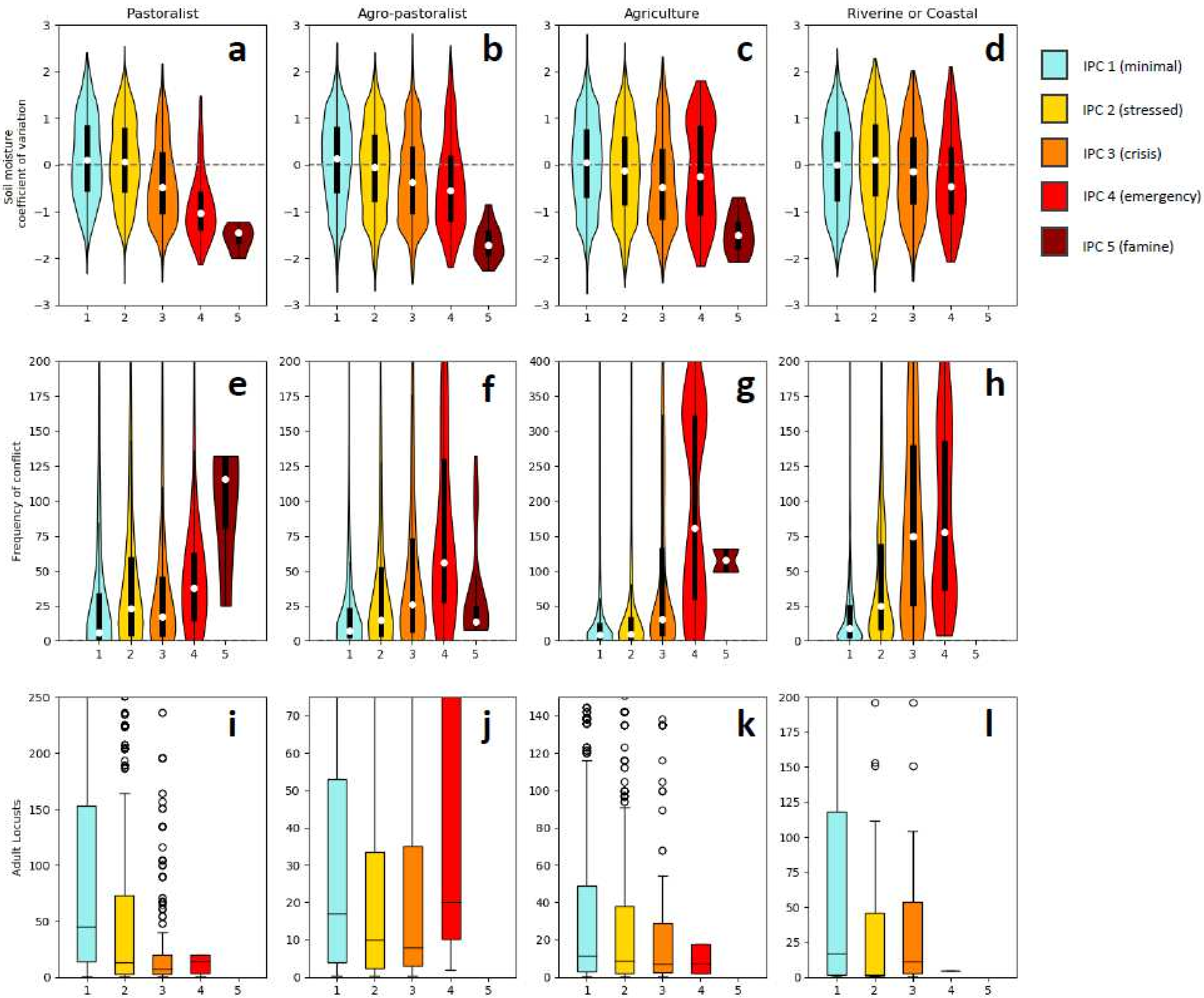

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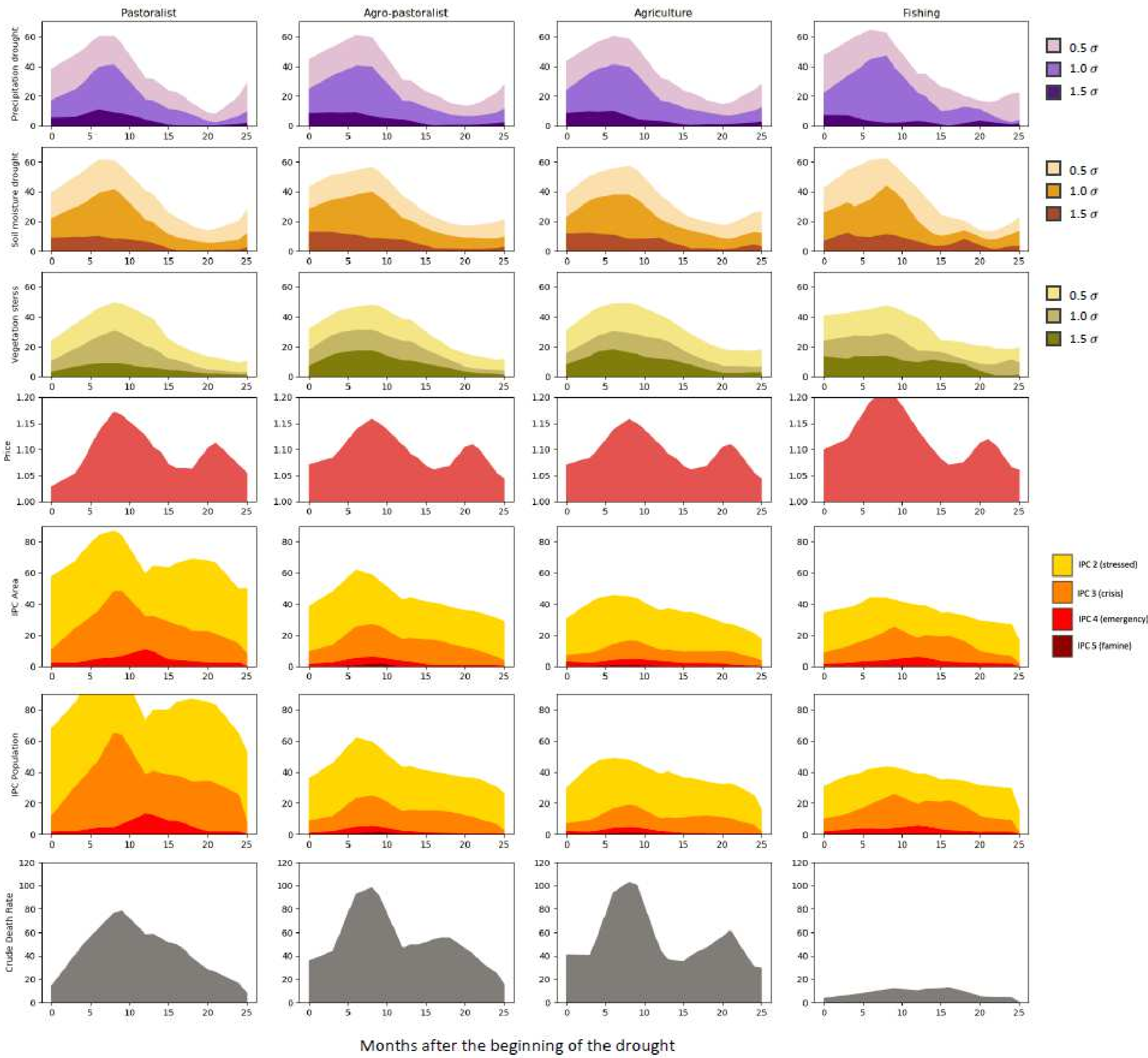

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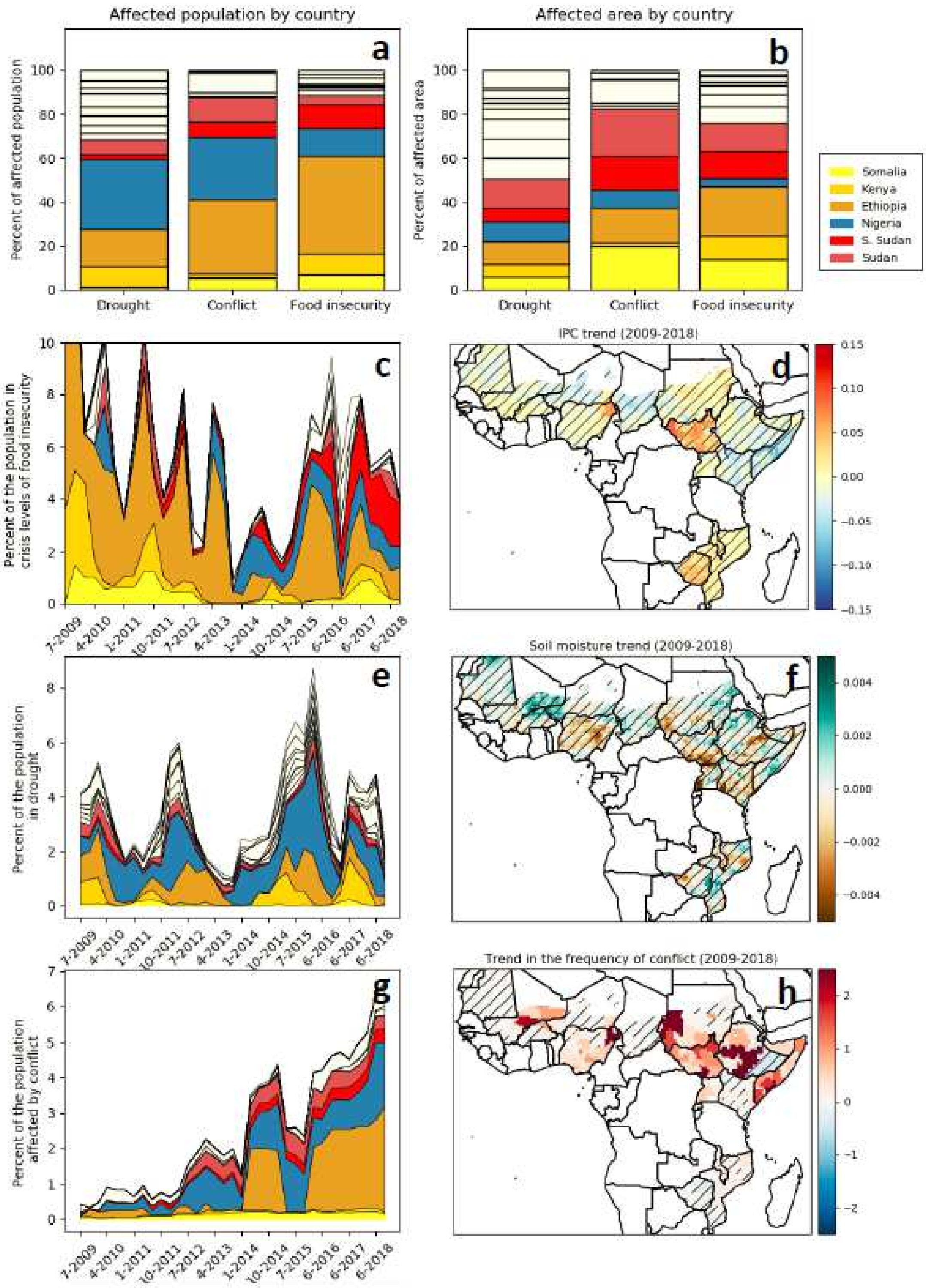

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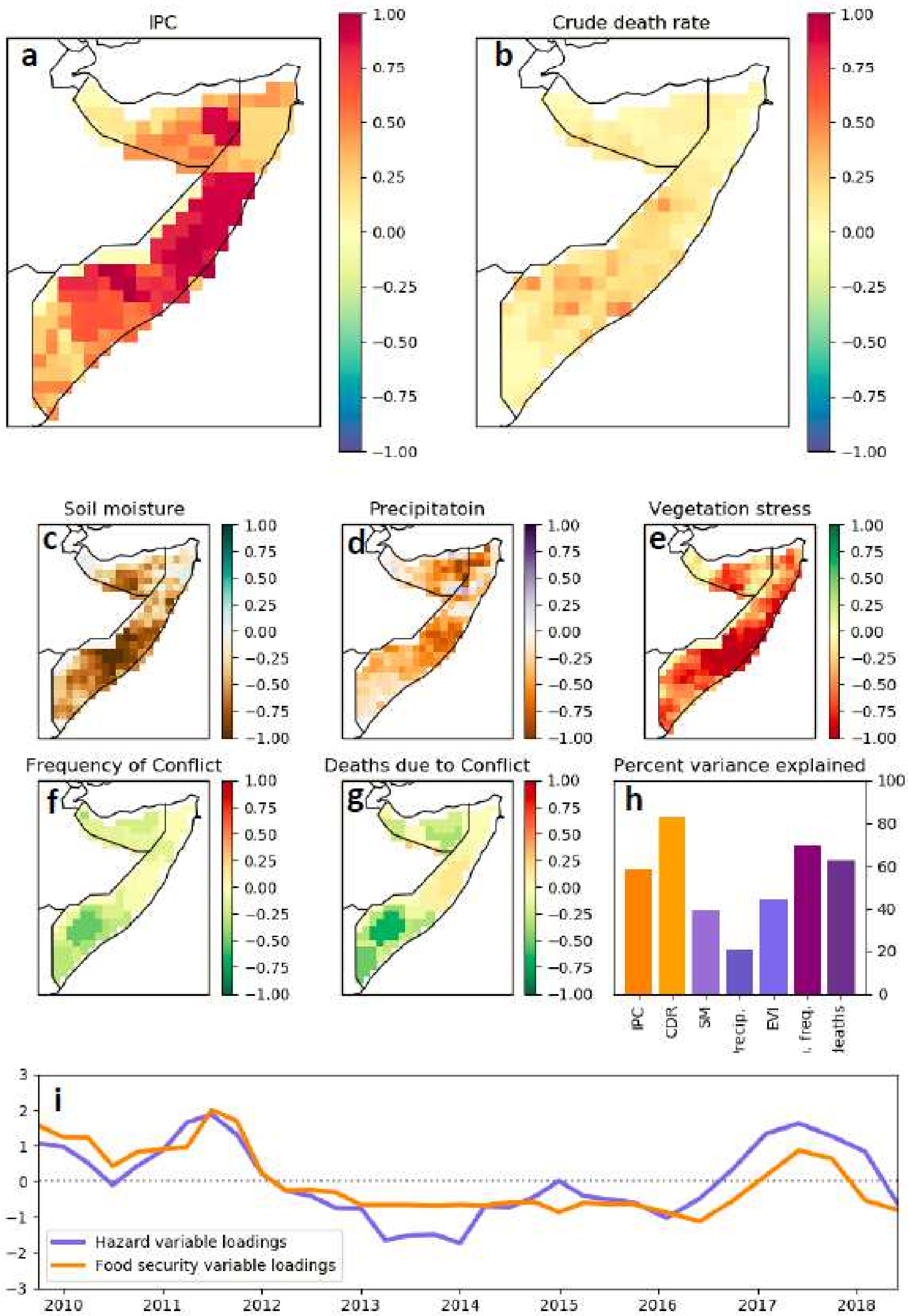

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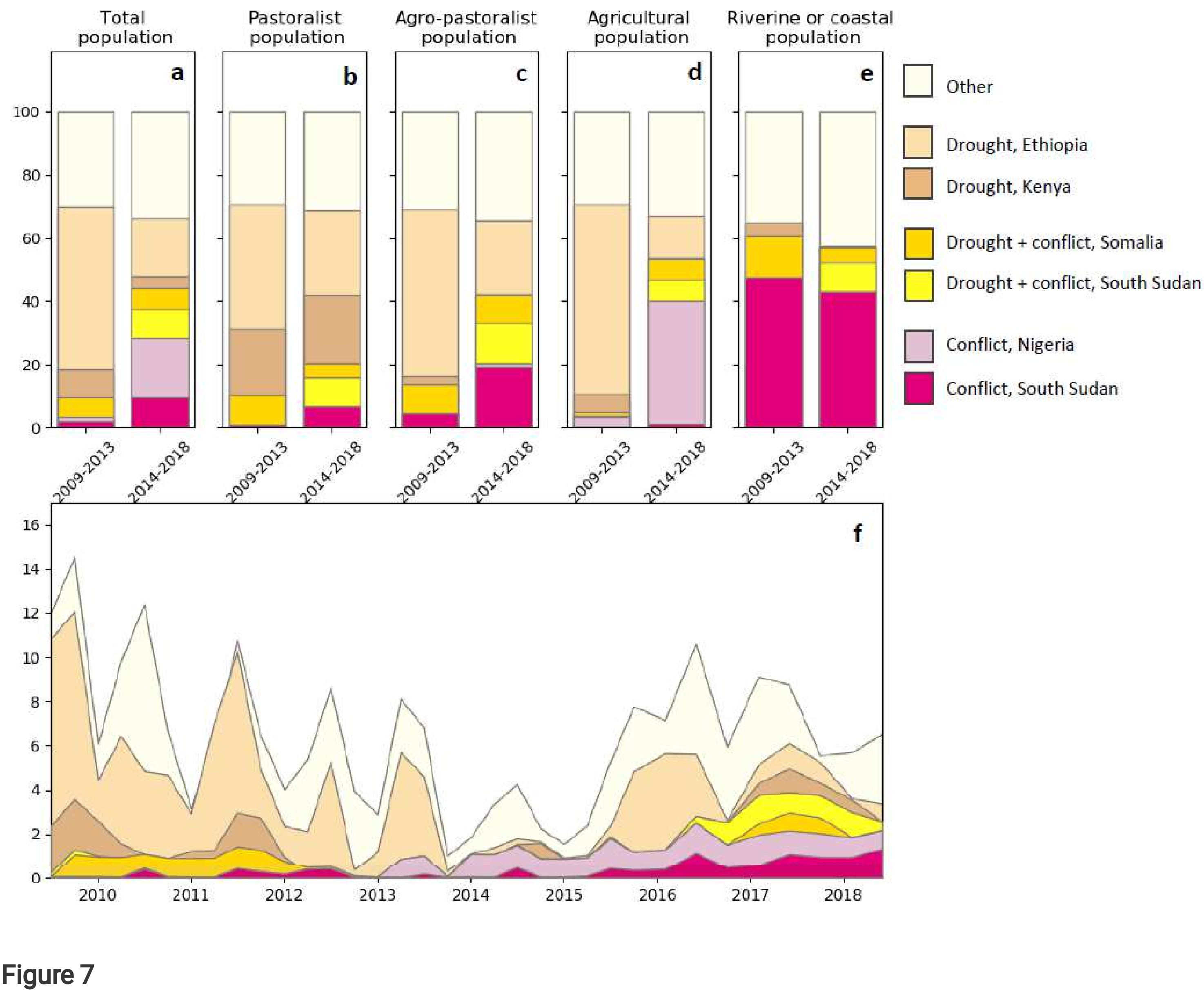

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Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryFigures.pdf