Food security and climate shocks in Senegal: Who and where are the most vulnerable households?

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A B S T R A C T

In the Sahel of West Africa, food security is a top development priority. Climate shocks threaten communities that rely on a single rainy season to grow crops and raise livestock. We exploit repeat surveys collected by the World Food Programme to quantitatively assess the year-to-year dynamics of household food security. Our methodology singles out the impact of climate shock on food access. We combine three variables, namely the Food Consumption Score, the Food Expenditure Share and the Reduced Coping Strategies Index to explore the access dimension of food security. Cluster analysis on the three variables leads us to 1) classify into categories, and spatially locate less and more food secure households; and 2) discuss the response of each category of household to seasonality and variability in climate. First, we find that in a drought year, some rural households – with average food security status – that normally do not use coping strategies actually have to use them. Second, we notice that food expenditure share increases in all categories of households, except one. Based on the different ways in which categories of households respond to (climatic) shock we recommend the design of targeted and more efficient interventions. We focus on Senegal because of the unprecedented opportunity to access repeat surveys, including an unusual one, taken during a *crisis* year. However, our methodology and recommendations can inform interventions in other Sahelian countries.

1. Introduction

Environmental shocks threaten food security in countries that rely heavily on rainfed agriculture and pastoralism (UNDP, 2007; Ludi, 2009). The Sahel of West Africa illustrates some of the most dramatic cases of recorded climatic change leading to environmental degradation, rainfall variability and famine (Gado, 1993; Batterbury and Warren, 2001; Mortimore and Adams, 2001; Rasmussen et al., 2016). In this region, food security has been a top government and regional issue since the repeated, severe droughts of the 1970s and 1980s. The distribution of food-insecure households within economies is unclear, but rainfall variability is expected to worsen food security in areas already stressed by hunger, malnutrition (Wheeler and Von Braun 2013) and food price hikes (Benzie, 2015; Kinda and Badolo, 2019).

We focus on Senegal because of a long-standing collaboration between the country office of the World Food Programme (WFP) and the

International Research Institute for Climate and Society (IRI). This collaboration aims to improve short-term response to climate-induced crisis based on in-depth understanding of vulnerability. Like other Sahelian countries, Senegal is highly sensitive to climate risk, especially droughts and floods, which worsens environmental degradation, poverty, and food insecurity.

Food security exists when "all people, at all times, have physical, social, and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). This definition illustrates food security as a concept involving multiple dimensions such as food availability, access, utilization, and stability (Gross et al., 2000). Measuring food security is complex (Barrett, 2010), and has evolved from focusing on food supply aggregated at national, regional and global levels to including food demand and access at the scale of households and individuals (Pinstrup-Andersen, 2009; Leroy et al., 2015). Climate shocks are known to
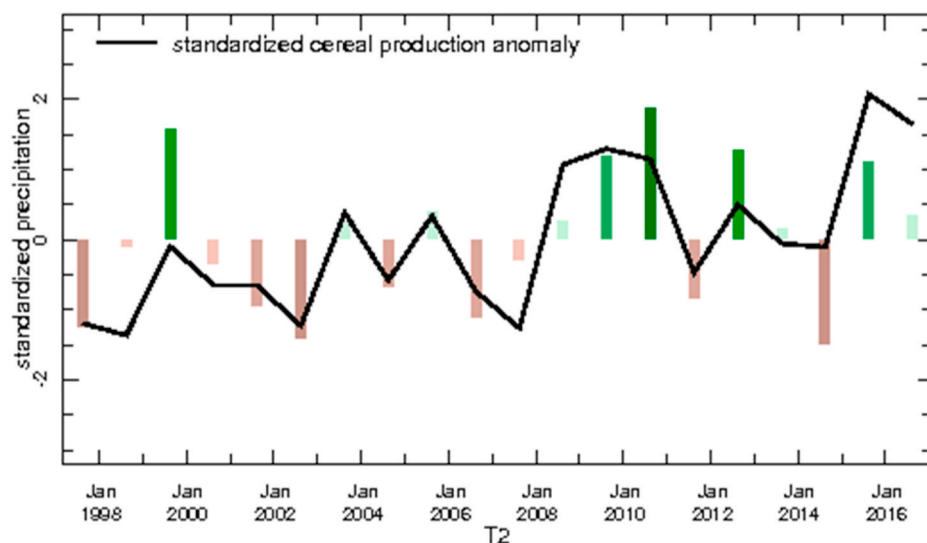
Fig. 1. Comparison of time series of standardized anomalies in precipitation and in agricultural production over the 20-year period between 1997 and 2016. Senegal-wide precipitation during the July to September core of the rainy season is represented in the color bars. Anomalies from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS; Funk et al., 2015) are averaged over 12.5 to 16.5°N and 17 to 12°W. Agricultural production is represented in the black line. It is the sum of millet, maize, sorghum and rice, from the national statistics published by FAOSTAT <http://www.fao.org/faostat/en/#home>. The correlation between the two timeseries is 0.70. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

affect crop yields (availability); food prices, agricultural household income and economic resources (access); malnutrition (utilization) and resource-based conflict (stability) (Gregory et al., 2005; IPCC, 2007; Schmidhuber and Tubiello, 2007; Brown and Funk, 2008; Burke et al., 2009; Battisti and Naylor, 2009; Wang et al., 2009; Jankowska et al., 2012; Lake et al., 2012; Brown et al., 2015; Gundersen and Ziliak, 2015; Hertel, 2016; Ochieng et al., 2016; Giannini et al., 2017; Niles and Salerno, 2018; Sawe et al., 2018; Kinda and Badolo, 2019). Severity of shock and resilience differ by location, time, and socio-economic status (Alinovi et al., 2010; Schmidhuber and Tubiello, 2007; Lobell et al., 2008; Gregory et al., 2005).

Here we explore a complementary approach to that most often used in studies of climatic impact on food security. It is attractive to quantify the relation between climate variability and crop yields (Schlenker and Lobell, 2010). Indeed, a precursor analysis by the Senegalese National Agency for Civil Aviation and Meteorology (ANACIM), WFP and IRI found major crops such as rice, millet, groundnuts, and sorghum to be highly sensitive to rainfall changes, leading to poor crop production in low rainfall years (ANACIM, WFP, IRI, 2012). The analysis presented in Fig. 1 supports the significant relation between crop production and rainfall. Rainfall averaged over a rectangular domain encompassing Senegal and depicted in the color bars (Funk et al., 2015), is compared with national cereal production, the sum of millet, maize, rice and sorghum (FAOSTAT), in the black line. The correlation between the two timeseries over 1997–2016 is 0.7. However, food availability by itself is not a strong predictor of food and nutrition security (Webb et al., 2006). In fact, in the Sahel, despite an increase in agricultural production between 1995 and 2016, undernourishment is rising rapidly (FAO, WFP, UNICEF, 2019). The relation between yields and food security is complicated by issues such as marketing, livelihoods, income and shocks (Wiggins and Keats, 2009). Therefore, rather than limiting ourselves to quantifying climatic impact on the food availability dimension of food security (through correlations of climate and crop yields), we define a measure of food security that highlights food access, and relate its year-to-year variation to the occurrence of climatic shock (Mousseau and Mittal, 2006; Bloem et al., 2009; Barrett, 2010).

We focus on Senegal, where household surveys are typically collected at national scale (Carletto et al., 2013). We envision this study to inform future studies on the differentiated impact that climate shocks have on less and more food secure households in Sahelian countries, where a unique and short rainy season is increasingly affected by anthropogenic climate change. Climate is a commonality among these countries. However, this region is diverse and complex in terms of culture, politics, and ecology (Raynaut, 2001). Potential causes of crisis

differ, with climate a *threat multiplier* to conflict, violent extremism and instability, which are presently greater concerns in some countries (i.e., Burkina Faso, Mali, Niger) compared to others (i.e., Senegal). Finer scale studies that look at factors affecting vulnerability to food insecurity in specific hotspots and that identify who the food insecure are provide the necessary baseline to anticipate crises of different nature, such as conflicts broadly described as ethnic, political or religious.

2. Methods

2.1. Capturing the multidimensionality of food security

No single indicator has been identified to comprehensively cover all four dimensions of food security at a time. Using different indicators makes it challenging to data collectors, analysts and users to have a comprehensive and harmonized understanding and measurement of food security (Bonnecase, 2012). Different indicators may serve different purposes. For example, the Integrated Food Security Phase Classification (IPC) is used to monitor and trigger humanitarian intervention. The most successful studies have been those that incorporated diverse indicators to capture the complexity of food security (FAO, 2013; Cafiero, 2012). Previous studies have looked at two or more indicators to get a comprehensive understanding of the different dimensions of food security (Maxwell et al., 2013; Maxwell et al., 2014; Ike et al., 2015; Leroy et al., 2015; Ike et al., 2017; FAO et al., 2019).

We explore the extent to which the access dimension of food security can be measured when data on dietary diversity and food frequency such as the Food Consumption Score (FCS) is triangulated with data on household food expenditure and other means or strategies of accessing food.

FCS is a household-level measure which is not sensitive to intra-household inequities in food access and consumption (International Dietary Data Expansion (INDDEX) Project, 2018). Therefore, it cannot be used for interventions that target individuals vulnerable to malnutrition such as women and children. Malnutrition is often measured through child stunting and wasting data. Stunting is defined as low heightfor age while wasting is defined as low weight for height due to unsatisfactory food consumption and poor health conditions stemming from widespread poverty (UNICEF, 2009). Stunting and wasting indicators are commonly calculated using cross-sectional surveys such as the Demographic Health Surveys (DHS) collected every five years in each country (Rabassa et al., 2012; Akombi et al., 2017a, 2017b; Alfani et al., 2018). FAO and USAID recommend the use of indicators such as the Minimum Dietary Diversity (MDD) for women aged 15–49 years old
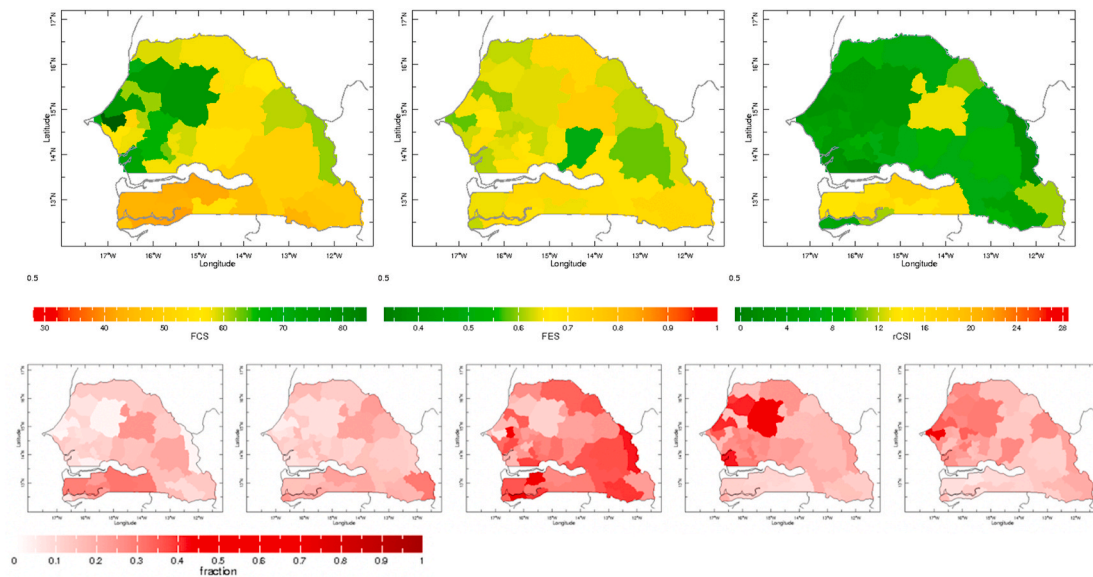
Fig. 2. Top row: department averages, over the three surveys, of the median values of FCS, FES and rCSI. Averages are computed as follows. First, for each survey, each variable's median value is computed over households in each department. Then, these median values are averaged over the three surveys. Bottom row: Average cluster frequency by department, going from the least food secure cluster on the left to the most food secure on the right. The percent of households in a department that belong to each cluster is first computed over each survey, then averaged over the three surveys. Shading from light to dark red indicates increasing percent values. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

and children 6–23 months old when individual dietary diversity information is needed to monitor diet quality or to provide targeted humanitarian assistance to the most vulnerable in resource-constrained settings (International Dietary Data Expansion (INDDEX) Project, 2018). Surveys are administered at individual level, but the indicators, based on a 24-h food consumption recall, are used for population-level analyses and interventions.

Linking FCS with Food Expenditure Share (FES) provides a better understanding of households' vulnerability to food security. FES, the ratio of food to total expenditures, focuses on cash expenditure on food and offers a good estimate of staple food price variations on household consumption quantity and quality (INDDEX Project, 2018). WFP analyses also capture food production in FES calculation. The percentage of cash spent on food is usually larger in poorer and more food insecure households (INDDEX Project, 2018; Smith and Subandoro, 2007). Adding the Reduced Coping Strategies Index (rCSI) to the analysis helps look at household responses to stabilize food access in times of crisis. rCSI evaluates asset depletion by measuring what people do to manage household food shortages. Coping strategies include relying on less preferred and cheaper foods; borrowing food; limiting portion size; favoring children consumption and restricting that of adults; reducing number of meals per day (Maxwell et al., 2008). The way a household withstands economic shocks depends on their livelihood strategy (Ellis, 1998). The higher the rCSI, the more food insecure a household is (Maxwell and Caldwell, 2008; Subedi and Kent, 2018). We apply cluster analyses to our three variables, FCS, FES and rCSI, to characterize the access dimension of food security at the rural household level, in its structural, i.e., average, and conjunctural, i.e., in response to climate shock, components. We *characterize less and more food secure households* based on these three variables, and examine *how these categories of households are differentially affected by environmental shocks*, notably drought. First, we describe the data, methods and results of cluster analysis across the three available surveys. We discuss our findings on variations in the classification across surveys, which we relate to climate. We demonstrate the importance of our results and conclude with recommendations. We plan to follow up on this study, which provides a quantitative definition of food security, with a study that further explores the relation of food security to livelihoods, specifically,

whether food security is higher when households have diversified livelihoods away from *climate-sensitive* income sources.

2.2. Materials

We use rural household survey data, collected from thousands of households in each survey, from the Comprehensive Food Security Vulnerability Analyses (CFSVA) conducted in Senegal in 2013, 2014 and 2016 by WFP's Vulnerability and Analysis Mapping (VAM) unit and its government and non-governmental partners (ENSAS, 2016; ERASAN, 2014; ENSAN, 2013). CFSVA examines *baseline* food security, i.e., during *normal* times (WFP, 2009). Household sampling is designed to result in robust variation at the level of the second-order administrative unit, which in Senegal is called *department*. In our study we endeavor to demonstrate the *research-grade* robustness of the data insofar as it pertains to the basic, repeated aspects of WFP CFSVA surveys. We focus on rural households because most are directly involved in climate-sensitive activities – such as rainfed agriculture and livestock husbandry and fishing – and are at increased risk of being food insecure following climate shocks (Cabral, 2010).

2.3. Methods

We analyze household survey data in two complementary forms: (1) We aggregate household data to the level of the 45 departments in Senegal (2) We apply the k-means clustering algorithm derived from Hartigan and Wong (1979) to household values of three variables, namely, the Food Consumption Score (FCS), the Food Expenditure Share (FES) and the Reduced Coping Strategies Index (rCSI), to classify food security condition.

In the top row of Fig. 2, each panel represents the average of the departmental median values of the three variables object of our study, computed over the three available surveys. Color scales are designed to represent less food secure conditions in yellow to red shading, and more food secure conditions in yellow to green shading. Generally speaking, there are more green departments in the north and center, and more orange departments in the south and east. FCS is negatively correlated with both FES and rCSI, with spatial correlations of the order of −0.5

Table 1

Mean values for each cluster of the three variables used to define the clusters. Cluster analysis is repeated to define a minimum of 3 and a maximum of 5 clusters using the 2013 survey.

	least food secure		intermediate	most food secure	
FCS	42.7		42.3	76.0	
FES	57.7		61.6	48.3	
rCSI	30.8		6.5	2.2	
FCS	40.2	44.3	44.5	78.2	
FES	59.0	57.2	61.8	47.5	
rCSI	39.5	18.6	3.1	2.1	
FCS	40.3	43.8	40.1	75.5	74.0
FES	59.1	57.3	60.7	67.3	36.2
rCSI	39.5	18.7	3.2	2.5	2.3

between FCS and FES, and of the order of −0.7 between FCS and rCSI.

3. Analysis and results

3.1. Describing household-level food security using cluster analysis

We use cluster analysis (Izraelov and Silber, 2019; Giannini et al., 2017; Borders et al., 2018) and spatial maps to describe household food security and help locate areas in need of attention to better inform the planning of targeted interventions (Borders et al., 2018). We focus on three complementary variables that combine access and stability dimensions of food security, namely, the food consumption score (FCS), the food expenditures share (FES), and the reduced coping strategies index (rCSI).

We first assess the robustness of our classification by varying the number of clusters retained, training our interpretation on the analysis of the 2013 survey. We try a minimum of 3 and a maximum of 5 clusters. The mean values of the three defining variables in this classification – FCS, FES, and rCSI – are reported in Table 1.

When we retain 3 clusters – see the top of Table 1 – the *least food secure* households are characterized by low mean FCS, high mean FES, and, notably, very high mean rCSI. The *most food secure* are characterized by high mean FCS, and lowest mean FES and rCSI. An intermediate cluster displays mean FCS and FES similar to the *least food secure*, but mean rCSI similar to the *most food secure*. When we add a cluster, that is, we repeat the analysis seeking to define four clusters – see the middle of Table 1 – the *least food secure* cluster splits into two, based on rCSI, with one cluster displaying very high rCSI and the other intermediate rCSI.

Adding a fifth cluster – see the bottom of Table 1 – splits the *most food secure* cluster into two, characterized respectively by high or low FES.

The 5-cluster solution for the 2013 survey is depicted in Fig. 3: each point in the 2-dimensional spaces defined by pairs of the three defining variables represents a household. Visual inspection of the three plots, depicting from left to right, the FCS-FES, FCS-rCSI and FES-rCSI spaces, shows that the overlap among dots of different colors is overall minimal, confirming that the algorithm has successfully separated 5 different food security situations. There are three clusters that essentially do not recur to coping strategies, in the three columns to the right at the bottom of Table 1. These households occupy complementary sub-regions spanning the FCS-FES space, on the left in Fig. 3. The less food secure cluster of the three, in orange, occupies the space defined by low FCS and high FES. The two more food secure clusters, in green and blue, occupy the space defined by high FCS, with high or low FES discriminating between the two. rCSI, the third dimension, is needed to separate the two least food secure clusters, in yellow and red, and discriminate between them. These become visible in the middle and right panels, where rCSI successfully stratifies them.

In sum, the three less food secure clusters, those characterized by a mean FCS around 40, are distinguished based on their recourse to coping strategies, measured by rCSI, which is high, intermediate or low, respectively in the red, yellow and orange dots in Fig. 3. On average, these three clusters spend similar proportions of income on food, but recur to coping strategies to different extent to supplement food purchases, in order to attain similar nutritional conditions, as measured by the food consumption score. The two more food secure clusters, those characterized by a mean FCS around 75, in green and blue in Fig. 3, are distinguished based on FES. The association between FES and food security is ambiguous, because the ratio taken between food and total

Table 2

Mean (and median, in parentheses) values of the three variables used to define the cluster. The analysis is repeated over the three surveys to define 5 clusters.

Food security status		least		intermediate		most
2013	FCS	40 (35)	44 (42)	40 (41)	76 (75)	74 (72)
	FES	59 (59)	57 (58)	61 (61)	67 (66)	36 (38)
	rCSI	40 (39)	19 (18)	3 (2)	3 (1)	2 (1)
2014	FCS	46 (44)	43 (42)	38 (40)	78 (77)	82 (83)
	FES	82 (85)	26 (29)	82 (83)	82 (82)	53 (56)
	rCSI	36 (35)	20 (18)	8 (7)	9 (7)	7 (5)
2016	FCS	50 (46)	52 (50)	44 (45)	85 (83)	65 (62)
	FES	44 (50)	69 (72)	71 (72)	68 (71)	18 (22)
	rCSI	32 (31)	15 (15)	3 (2)	3 (1)	5 (3)
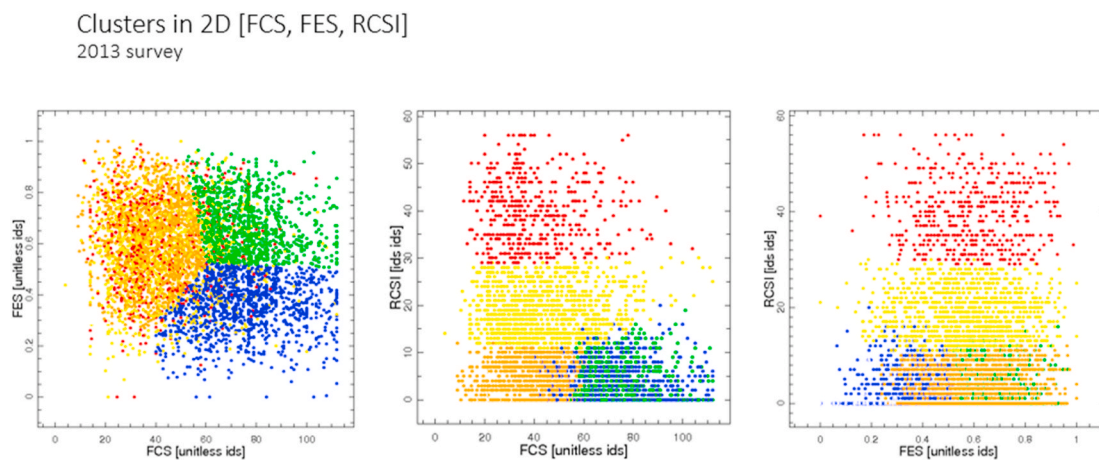
Fig. 3. 2-D scatterplots of the variables defining the 5 food security clusters in the case of the 2013 survey. Clusters are depicted in red, yellow, orange, green and blue dots, from least to most food secure. Clusters in this order correspond to the columns from left to right at the bottom of Table 1, and in all other Tables. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 3
The percentage of rural households belonging to each cluster, from least in the left, to most food secure in the right, across the three surveys.

Food security status	least		intermediate		most
2013	8.8	20.9	27.2	19.6	23.4
2014	22.4	6.0	30.9	24.3	16.5
2016	7.7	15.8	33.1	23.9	19.5

expenditures masks the *wealth* of a household: a household could spend little on food in absolute terms, which may be considered a measure of food insecurity, or spend little in proportion, because it spends a lot in total, a sign of wealth and likely food security. In this survey we interpret low FES to be the prerogative of more food secure households. This interpretation is empirical, and it is based on the negative spatial correlation [Pearson $= -0.49$; Spearman $= -0.55$] between FCS and FES maps in the top row of Fig. 2.

We repeat the analysis on the two subsequent surveys, taken in 2014 and in 2016. In Table 2, we report mean and median values of the three defining variables by cluster, across the three surveys. Results confirm the robustness of the classification: two more food secure clusters are first separated from three less food secure clusters based on FCS, then the three less food secure clusters are distinguished based on rCSI, and finally the two more food secure clusters are distinguished based on FES. In Table 3, we report the percent of rural households belonging to each cluster with respect to the total number of rural households interviewed by each survey.

In the bottom row of Fig. 2, we plot maps of the average cluster frequency by department, that is, the average percent of households belonging to each cluster across the three surveys. The two more food secure clusters are prevalent in the northwestern quadrant of the country. The two less food secure clusters are prevalent in the south and east of the country. The remaining *intermediate* cluster, characterized by low FCS and rCSI, and high FES, is overall the most frequent. On average, 30% of households fall into this cluster, which is essentially equally prevalent everywhere, with a notable minimum in the northwestern quadrant.

As previously noted, the three surveys were taken not only in

different years – 2013 (ENSAN, 2013), 2014 (ERASAN, 2014) and 2016 (ENSAS, 2016) – but also in different months – respectively, in June, during the lean season, in October, at the beginning of harvest, and in January, after the end of harvest. If seasonality dominated variation in food security, we would expect 2013 to express overall the least food secure conditions, because taken during the lean season, and 2016 the most food secure, because taken after income from the agricultural season is realized. Measuring food production – which is out of scope for this study– could provide more information on these annual differences.

Conditions are indeed largely more food secure in 2016 (Table 2). The mean FCS is generally higher, recording the highest value among the three surveys for all clusters except for the most food secure. Mean rCSI is generally lower, especially in the less food secure clusters.

Seasonality can explain why 2016 is the most food secure survey, especially in relation to 2013. But it cannot explain why the most dramatic change, indicative of a widespread decrease in food security, occurs in 2014. A first macroscopic change in 2014 compared to the other two years is the near-universal increase in mean FES (see Table 2). This change is especially stark when compared to the 2013 survey. Secondly, mean rCSI increases in the three clusters that recur the least to coping strategies, those in the three columns to the right in Table 2. Finally, the second least food secure cluster loses definition compared to the other two surveys, where it occupies the space of intermediate rCSI values. Indeed, a check on the frequency of occurrence of similar clusters across surveys, in Table 3, reveals that this cluster thins out in 2014, where it accounts for only 6% of households, against 21 and 16%, respectively, in 2013 and 2016.

Further, comparing across surveys the two least food secure clusters, those that recur to coping strategies the most, it becomes apparent that in 2014 the high rCSI cluster gains mass at the expense of the intermediate rCSI cluster, meaning that more households recurred to more coping strategies. The most frequent intermediate cluster, despite increases in food expenditures and in recourse to coping strategies, suffers the most, as signaled by mean and median FCS values that dip below 40 in Table 2. In 2014, there is also a shift toward reduced food security among the more food secure clusters. The most food secure shrinks in size, in favor of the second most food secure. Again, this is especially true in relation to 2013, signaling an increase in FES in a significant

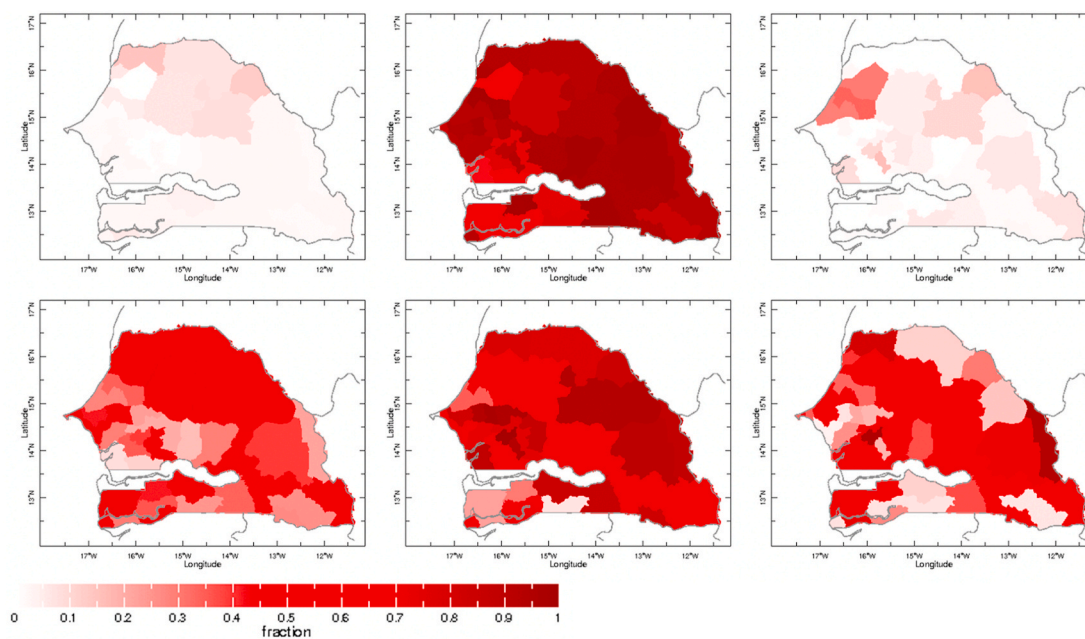**Fig. 4.** Percentage of households complaining about insufficient rains (top) and food price hikes (bottom), across the three years surveyed: 2013 on the left, 2014 in the center, and 2016 on the right. Shading from light to dark red indicates increasing percent values. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)
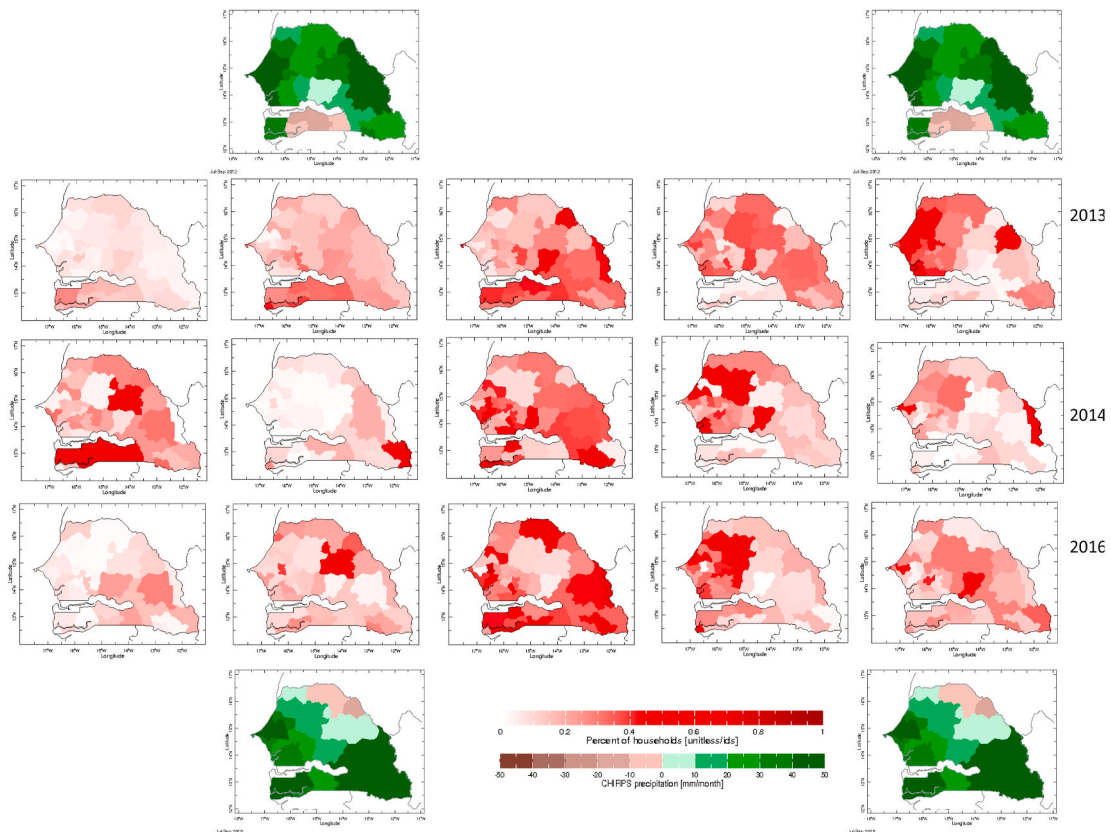
Fig. 5. Comparison of spatial patterns of rainfall and cluster frequency anomalies. The three central rows represent cluster frequency for each survey – 2013 to 2016, top to bottom, respectively. They represent the actual percent of households belonging to each cluster in each year, which can be compared to their average, depicted in the bottom row of Fig. 2. The darker the red hue, the larger the portion of households belonging to the cluster. Rainfall anomalies, negative in brown and positive in green, are depicted in the maps above and below the three central rows, and correspond to the rainy seasons of relevance to the 2013 and 2016 surveys, respectively. The 2013 rainfall anomaly map, above the three central rows, is characterized by positive anomalies in the center and north of the country, and by negative anomalies in the south of the country. It shows matching variations in the frequencies of the most food secure (more households) and second least food secure (fewer households) clusters, respectively, in the north and south of the country, in the top of the three central rows. Similarly, for the 2016 rainfall anomaly map below the three central rows. In this case variations are reversed between northern and southern departments, with increased frequency of the second least food secure cluster in the north, and of the most food secure cluster in the south, in the bottom of the three central rows, corresponding to negative and positive precipitation anomalies in the north and south respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

fraction of the more food secure households, visible in the median and mean cluster values reported in Table 2.

3.2. Variation in food security in response to climatic shock: the drought of 2014

The availability of three large-scale household surveys provides an unprecedented opportunity to quantitatively assess the year-to-year dynamics of household food security. Here we are interested in testing the impact of climatic shock on household food security in relation to more common socio-economic shocks. We relate households' own assessment of how they were affected by two categories of shock, climate/environmental and health/socio-economic, to climatic conditions, characterized by variation in total seasonal rainfall during the rainy season (July–September) immediately preceding the taking of the surveys. The three rainy seasons in question, those of 2012, 2014 and 2015, are strikingly and complementarily different among the most recent 20 years (Figs. 1 and 5).

2012 and 2015 are the second and fourth wettest years since 2000, respectively (Fig. 1), with complementary spatial patterns in anomaly (Fig. 5): 2012, above the three central rows in Fig. 5, is relatively deficient in the center and south, and abundant in the north, while 2016, below the three central rows in Fig. 5, is deficient in the north. In contrast, 2014 is not only the driest year since 2000 (Fig. 1). It is also

generally deficient across the country (not shown). Following the below-average rainfall in 2014, FEWSNET (2014 & 2015) reported poor cropping and grazing conditions, classifying central Senegal as stressed (IPC Phase 2) and northern Senegal as an area in crisis (IPC Phase 3) in early 2015. In 2015, households depleted their food stocks earlier than normal, in March instead of June, and relied on market purchases to meet their food needs. Prices for imported staples such as rice were stable, but prices for local staples were above seasonal averages because of higher domestic demand. In March 2015, FEWSNET expected the share of food expenditure to be higher than usual. For these reasons, poor households, who could not afford expenditures on health, education and farm input among others, were expected to be stressed (IPC Phase 2) between March and April 2015.

CFSVAs, the kind of surveys studied here, are usually taken during *normal times*. The questionnaire includes questions on shocks experienced by households in the last 6 or 12 months. Participants are asked to choose potential answers from a list of options. These options are related to health, accident, death, insufficient rains, food price hikes, input price hikes, and conflicts, among others (ENSAS, 2016; ERASAN, 2014; ENSAN, 2013). The analysis of this data shows that in *normal times* far fewer households complain about climate or environmental shocks such as insufficient rains, pest invasion, flooding or bush fires, compared to health or socio-economic shocks such as illness or death in the family, increase in the prices of food and agricultural inputs or decrease in prices

of products sold. To contrast the recurrence in time of complaints about the different types of shock, in Fig. 4, we map the percent of households complaining about insufficient rains, an environmental shock, and about an increase in food prices, a socio-economic shock, across the three surveys.

Indeed, overall larger percentages of households, across clusters and departments, consistently complain about socio-economic shocks in the surveys analyzed here. In 2013, a minimum of 2.4% of households in the most food secure cluster, a maximum of 5.6% in the least food secure households, and an overall 4% of rural households complain about insufficient rains. In 2016, the same rates are 5.2%, 8.5% and 5.9%. In contrast, in 2013 a maximum of 46.3%, among least food secure households, a minimum of 35.3%, among households in the intermediate cluster, and an overall 39.7% of rural households complain about an increase in food prices. In 2016, the same percentages are 63.2, 33.8 and 42.2%. In comparison, what happens in 2014, in the middle column of Fig. 4, is extraordinary: 84.3% of all (rural) households complain about insufficient rains, with all clusters recording complaint rates of 80% or higher. 70.9% of all households complain about an increase in food prices, with all clusters recording rates of 65% or higher. In 2014, not only do complaints about insufficient rains increase many-fold. Complaints about food prices also increase, and most significantly so for the two more food secure clusters, which see rates of complaints approximately double.

4. Discussion

We used cluster analysis to find out *who and where the most and least food secure households are*, and *how they are differently affected by environmental shocks*, especially drought. Despite the surveys not being *panel data*, or exact repetitions, because the households interviewed are not the same, repeating the analysis on the different surveys results in the same classification scheme. As such, the classification reveals a robust depiction of structural food insecurity. The cluster analysis is also dynamic, in the sense that variation in the frequency of household membership in a cluster across surveys sheds light on conjunctural response to climatic shock.

4.1. Food security classification

We characterized the *who* through the distinction about how nutrition is achieved, whether through or despite coping strategies, in the case of the less food secure, or through expenditures, in the case of the more food secure. About 30% of households fall in one of the two least food secure categories, 30% fall in the intermediate category, and 40% in the two most food secure category. Categories are defined by a sort of *tree*, with FCS discriminating between less and more food secure, then rCSI among the less food secure, and FES among the more food secure. Households can move between categories, either by changing rCSI, for least food secure households or by changing FES, for most food secure households. In the global drought year sampled by the surveys analyzed, 2014, mean and median rCSI increased in the clusters where it is usually lowest, meaning more of the households that normally do not recur to coping strategies actually did. Mean and median FES increased across clusters (with the exception of the one cluster that lost mass, the second from left in Tables 2 and 3).

4.2. Spatial distribution

We identified *where* less or more food secure clusters are distributed across the country (Fig. 2). The least food secure are in the south and east, which is not where one would expect them to be, if climate were the dominant explanation, because the south is wetter – the rainy season is longer, and seasonal rainfall accumulation is higher. Comparing data across seasons and years shows that conjunctural constraints – such as occasional droughts – may impact food security in a specific season or

year, whereas long-term or 'structural' food security is likely primarily affected by economic constraints (e.g., food price hikes and access to farm inputs), 'land-lockedness with respect to Dakar', including the conflict in Casamance. If mismanaged, conjunctural challenges could also turn into additional structural constraints in the future.

The fact that the most food secure are in the northwest poses the question about the persistent droughts of the 1970s and 1980s possibly having reduced dependence on climate-sensitive economic activities in the long run (Davies 2016; Toulmin 1986). Answering this question would require an analysis of livelihoods which we intend to follow up on, to find out more about the nature of livelihood activities, main sources of income and coping strategies (e.g., climate or non-climate-sensitive) within each type of cluster.

The intermediate cluster, which is the most frequent, is relatively non-descript spatially, in the sense that departments with relatively high frequency of this cluster can be found in the south, east, center (groundnut basin) and north, especially along the Senegal river. It appears to define the *average* rural household in Senegal, 'hanging in there': it achieves barely sufficient nutrition, spending a significant portion of income on food, but not recurring to coping strategies significantly, at least not until drought hits.

4.3. Variability and seasonality

We assessed how differently households are influenced by environmental shocks, namely drought. This assessment was made possible because one of the years during which CFSVA data was collected, 2014, stood in stark contrast to the other two as a *global* drought year, that is, a year of insufficient rains everywhere in Senegal. CFSVAs are usually taken in *normal* periods, that is, not during a *crisis*. The analysis of the CFSVA data on the type of shocks that households experienced in the six months prior to the taking of the survey shows that the impact of climate is usually circumscribed, and of lesser relevance than the impact of socio-economic and health shocks. In contrast, the sampling of the global drought year in 2014 shows that drought occurrence has an impact, generally reducing food security. The impact of drought is manifest in households' direct self-assessment of climatic shock (in the percentage of households complaining about insufficient rains), and indirectly, in the overall tendency of the variables analyzed to take on values consistent with increased food insecurity (e.g., higher FES and rCSI in an attempt to maintain similar FCS).

Spatially coherent subnational patterns of wet and dry have an impact on cluster frequency. In the central rows in Fig. 5, we depict the actual frequency in cluster membership for each year. For example, the darker hues in the leftmost column in 2014 show that the least food secure cluster gains households in this year compared to 2013 and 2016. The rightmost column shows the complementary change: fewer households belonging to the most food secure cluster in 2014, compared to 2013 and 2016. Relatively dry conditions, in the south and center in 2013 and in the north in 2016, increase the frequency of the second least food secure cluster, which is more prevalent in the south in 2013 and in the north in 2016. Complementary patterns of relatively wet conditions are consistent with an increase in the most food secure clusters in the west and north in 2013, and in the south and east in 2016. Differences between 2016 and 2013 can be ascribed to seasonality, in the sense that to the extent that FCS is higher in 2016 than in 2013, it is consistent with the 2016 survey being taken after harvest, while the 2013 survey is taken during the lean season. But the globally lowest food security outcome in 2014, known as a drought year, cannot be ascribed to the month/season the survey was taken.

5. Conclusions

Climate – which is central to this study– is a key feature shared by Sahelian countries, in the midst of their social, economic, political and ecological differences. Increasing violent extremism and political

Table 4

Differentiated recommendations based on food security cluster.

Food security status	least		intermediate		most	
Undertake lifesaving activities	x	x				
Grow school feeding programs	x	x	x		x	x
Treat moderate acute malnutrition	x	x	x			
Develop weather index insurance, and FFA		x	x		x	x
Promote Inventory Credit System			x		x	x
Increase savings, credit and local food procurement					x	x

instability create gaps in agricultural and development policies across this region. Researchers have shown a circular link between food insecurity and conflict in the Sahel and argued that improving food security could help reduce tensions and promote stability (Hendrix and Brinkman, 2013). While some countries such as Senegal are acclaimed for their stability, others, such as Burkina Faso, Mali and Niger, have grown unstable (Benedikter and Ouédraogo 2019; Marc et al. 2015). These dissimilarities – which add a layer of complexity to the drivers of food insecurity – call for particular case studies. We explored the case of Senegal. However, our methodology –which singles out the impact that climate shock has on food security status– can inform WFP's work in its countries of intervention and that of other agencies (i.e., FAO, FEW-SNET) and local efforts working to eradicate hunger.

Identifying the most vulnerable populations to food insecurity and their sensitivity to climate shocks, as is the case in this study, will help prioritize interventions to support at-risk populations. Prioritizing is essential, especially as countries tackle challenges of diverse nature, including conflicts. Going forward, policies and interventions in times of crisis and programs aimed at improving food security could benefit from the recommendations listed in Table 4. The proposed solutions can be used following an assessment of the characteristics of the households involved (i.e, low FCS, high rCSI, or high FCS, low FES, etc.).

Lifesaving activities (i.e., general and targeted food distribution) could be developed to benefit the two less food secure clusters, those that recur to high and intermediate numbers of coping strategies, and appear to be structurally food insecure. School feeding programs could help reduce child hunger and absenteeism and boost learning abilities. Nutrition-sensitive Home-Grown School Feeding (HGSF) could address moderate acute malnutrition issues. HGSF involves food produced locally to empower local farmers and enhance regular access to nutritious and diverse food (Gelli et al., 2010). Increased food demand improves the income and food security of local farmers, including women groups (Masset and Gelli, 2013).

Different consideration should be given to the *intermediate cluster,* representative of the *average rural household,* perhaps starting from an in-depth analysis of livelihood strategies to understand what sets apart this cluster from the two least and most food secure clusters. Developing resilience could prevent these households from becoming less food secure. Resilience initiatives could include weather index insurance to pay out benefits based on insufficient rainfall. Food Assistance for Asset (FFA)– including community involvement in building or fixing assets (i. e., roads, wells, forests) in exchange for cash, voucher or food transfers – could strengthen long-term food security. The Inventory Credit System (ICS), locally referred to by the French word of *warrantage,* could improve farmers' income and secure food (Tabo et al., 2011). At harvest time, instead of selling their grain for low prices, ICS allows farmers to store their production in the warehouses of farmers' associations for cash loans to satisfy urgent needs. About 4–5 months post-harvest, when market supply declines, farmers sell deposited grains at higher prices to reimburse their credit, with interest. Similar resilience activities – plus access to credit and savings – and school feeding programs should also be encouraged in more food secure clusters. These recommendations could trickle down and help realize other development goals – such as education and health– intertwined with food security (Lake et al., 2012;

Gundersen and Ziliak, 2015).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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