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ORIGINAL PAPER

Exploring the impact of the 2008 global food crisis on food security among vulnerable households in rural South Africa

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Abstract Recurring food crises endanger the livelihoods of millions of households in developing countries around the globe. Owing to the importance of this issue, we explored recent changes in food security between the years 2004 and 2010 in a rural district in Northeastern South Africa. Our study window spans the time of the 2008 global food crisis and allows the investigation of its impacts on rural South African populations. Grounded in the sustainable livelihood framework, we examined differences in food security trajectories among vulnerable sub populations. A unique panel data set of 8,147 households, provided by the Agincourt Health and Demographic Surveillance System (Agincourt HDSS), allowed us to employ a longitudinal multilevel modeling approach to estimate adjusted growth curves for the differential changes in food security across time. We observed an overall improvement in food security that leveled off after 2008, most likely resulting from the global food crisis. In addition, we discovered significant differences in food security trajectories for various sub populations. For example, female-headed households and those living in areas with better access to natural resources differentially improved their food security situation, compared to male-headed households and those households with lower levels of natural resource access. However, former Mozambican refugees witnessed a decline in food security. Therefore, poverty alleviation programs for the Agincourt region should work to improve the food security of vulnerable households, such as former Mozambican refugees.

Keywords South Africa · Agincourt · Food security · Growth curve models · Natural resources · Global food crisis

Introduction

Maintaining health and quality of life depends on access to nutritious and diverse food. As a result, civilizations have

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developed systems of reliably and efficiently producing and distributing food, and in contemporary times, access to food has increased and become more predictable. As an indication, the number of undernourished individuals declined from an estimated 980 million in 1990 to 1992, to approximately 850 million in 2010 to 2012 (FAO, WFP, and IFAD 2012). Most of this progress, however, occurred before the 2008 food crisis, after which the advances in reducing hunger leveled off (FAO, WFP, and IFAD 2012). Despite the technological capacity to produce sufficient amounts of food for the global population, structural and political barriers inhibit delivery (Sen 1983). In addition, new global challenges, such as climate change, can potentially slow or reverse progress toward a world without hunger (Wheeler and von Braun 2013).

Food insecurity occurs when an individual has limited or uncertain availability of nutritionally adequate and safe food, or limited or uncertain ability to acquire acceptable food in socially acceptable ways (Anderson 1990). Food insecurity proves to be a global challenge, but the African continent experiences particularly high levels of hunger (FAO, WFP, and IFAD 2012). Further, the global food crisis in 2008 hit African nations hardest resulting in substantial increases in food prices and associated food riots across the globe (Maes et al. 2010; Hadley et al. 2011). The price of nearly every agricultural commodity sharply increased in 2007 and 2008, creating a global food price bubble. The price of sweet potatoes in Mozambique, for example, more than doubled from mid-2006 to August 2008 (von Braun 2008). The increase in food prices undermined the food security and threatened the livelihoods of the most vulnerable by eroding their already limited purchasing power. The urban and rural poor suffered most, because they spent a large portion (50–70 %) of their income on food and had little capacity to adapt as prices rose and wages for unskilled labor failed to adjust accordingly (von Braun 2008; Hadley et al. 2011).

Scholars have speculated much about the underlying causes of the 2008 food crisis. Contributing factors at the macro-level include higher oil prices, which impacted food production and processing costs, the use of food crops for biofuel production in the U.S. and Europe, growing meat consumption that stimulated increased demand for animal feed, poor harvests in major agricultural regions, and consistent underinvestment in agriculture over past decades, resulting in agricultural production that lagged behind population growth (Benson et al. 2008). In addition to these macro-level factors, several socio-demographic factors predispose individuals and households to a higher likelihood of hunger. Health status, such as HIV/AIDS and associated deaths of breadwinners (Kaschula 2008; Murphy 2008) as well as the stigmatization of refugees and female headed households (Barrett 2002; Hadley and Sellen 2006; Compton et al. 2010) are correlated with hunger. Effective response to food security crises requires an understanding of such differential vulnerabilities (Benson et al. 2008).

Unfortunately, little research has investigated the intersection of broad scale food crises and household- and individual-level vulnerabilities (Compton et al. 2010). This project aims to begin filling the gap. We explored changes in food security in a relatively poor, underserved region in rural South Africa before, during and after the 2008 global food crisis. More precisely, we asked: 1. *Has food security among households in rural South Africa changed between 2004 and 2010?* and 2. *Did changes in the food security situation differ for marginalized populations?* Answers to these questions may help policymakers improve the design, timing, and selection of target groups for programs intended to enhance food security.

Theoretical framing and literature review

We used the "Sustainable Livelihoods" (SL) framework (Carney et al. 1999) as theoretical grounding for this study, as it usefully reflects the diversity of livelihood strategies in developing countries, including farming, off-farm employment, and the use of natural resources employed by rural households to maintain livelihood security (De Sherbinin et al. 2008).

Livelihood security constitutes a necessary, and often sufficient, condition for food security and serves as a broader, useful concept for practitioner and policymakers, due to its longer-term perspective (Devereux and Maxwell 2001). Households typically have access to a variety of livelihood capitals, and the level of access, as well as the degree of diversification, determines the vulnerability towards food insecurity (c.f., Ellis 1998). The SL framework groups resources into five classes, referred to as livelihood capitals (Carney et al. 1999), including: human capital, physical capital, financial capital, social capital, and natural capital, which are employed through various, interacting livelihood strategies that either diminish or increase pools of available capital (Nawrotzki et al. 2012). In the following paragraphs, we describe linkages specifically between the various capitals and food security.

Human capital Education, employment status, and the number of individuals at the household-level able to engage in livelihood activities reflect human capital (Saenz and Morales 2006). A higher percentage of working household members may improve food security due to a larger amount of pooled income (c.f., Hadley et al. 2011). Similarly, higher levels of education may improve job opportunities, increase the overall levels of income, and might foster innovativeness of households to better cope with adverse livelihood conditions (c.f., Compton et al. 2010).

In contrast, the death of a prime age adult (often attributed to HIV/AIDS in Africa) detrimentally impacts households' human capital. For the South African context, Kaschula (2008) found that a household's AIDS status significantly reduced food security. Households that have experienced the loss of a prime age adult frequently struggle to feed their members due to reduced labor productivity and social stigmatization (Murphy 2008; Tsai et al. 2011; Twine and Hunter 2011). In the face of deteriorating livelihoods, AIDS-impacted households frequently rely on natural resources and home or kitchen gardens to replace purchased foods (Hunter et al. 2007; Murphy 2008; Hunter et al. 2011).

Physical and financial capital In poor communities where income can vary greatly throughout the year, assets (physical capital) are a more robust measure of wealth, compared to monetary earnings (financial capital). As such, wealth indices that combine various household possessions can be effective measures of socioeconomic status (e.g., Mberu 2006; Nawrotzki et al. 2012). Wealthier households are likely to have more resources available for food purchase, and are able to sell or exchange physical capital for food (Devereux and Maxwell 2001; Kirkland et al. 2013).

Social grants also play an important role in South African livelihoods (Schatz et al. 2012; Goudge et al. 2009). The South African government provides five types of social grants and establishes eligibility using income-based means tests (ODI 2006). Social grants include old age pension, disability grants, child support grants, foster child grants, and care dependency grants. These provide a reliable safety net for the poor and significantly improve households' well-being and food security (Goudge et al. 2009; Patel and Hochfeld 2011; Schatz et al. 2012).

Social capital Individuals can draw on social capital to reduce food insecurity in times of crises (Hadley et al. 2007; Martin et al. 2004) through gifts, to access credits, as well as to borrow and sell goods or services (Goudge et al. 2009). In our study site, two groups had largely different levels of access to social capital: migrants and refugees. Many households in Agincourt have migrant members residing elsewhere (Hunter et al. 2013). These migrant households may be able to access different support systems through extended connections to other communities. In addition, migrant households benefit from a wider labor network with more choices for income generation and possibly higher returns for their efforts. These connections may result in remittances and added livelihood and food security (Collinson et al. 2006; Hunter et al. 2011).

In contrast, refugee households may have lower levels of social capital. During the 1990s, the study region experienced a high influx of refugees from neighboring Mozambique (Madhavan et al. 2009) as a result of the nation's civil war during 1983–1992 (Hargreaves et al. 2004). The South African government granted official refugee status in 1993, and citizenship became available in 1996. However, Mozambican households continue to face structural, social, and cultural barriers that prevent equal access to resources (Collinson 2010) with potentially adverse impacts on food security (Barrett 2002; Hadley and Sellen 2006).

Natural capital Within the Agincourt region, rural households employ wild natural resources to meet daily needs, such as food and cooking fuel (firewood), and for income generation through the sale of products, such as marula beer or palm brushes (Shackleton and Shackleton 2004). Natural resources often constitute safety nets (Shackleton and Shackleton 2011) and help maintain a certain level of food security in times of crises.

Household Age and gender composition We expect households with a large proportion of dependent members, such as children and/or elderly, to experience more food insecurity compared to households composed largely of working age adults. Still, government-funded social grants for children and senior citizens provide a small but stable income positively impacting South African food security (Patel and Hochfeld 2011; Schatz et al. 2012). With regard to gender, prior research showed that female-headed households largely occupied the lower percentiles of the socio-economic stratum (Collinson 2010), and may face greater danger of food insecurity compared to their male-headed counterparts (Compton et al. 2010; Hadley et al. 2011).

Study site and data

We used an innovative panel data set provided by the Agincourt Health and Demographic Surveillance System (Agincourt HDSS), managed by the Rural Public Health and Health Transitions Research Unit of the South African Medical Research Council (MRC) and the University of Witwatersrand (Wits). The Agincourt study site is located in a rural sub-district in the Mpumalanga Province, South Africa (AHDSS 2009) (Fig. 1). The 400 km^2 area is situated near the Mozambique border, approximately 500 km northeast of Johannesburg with a total surveillance population of 70,527 people living in 11,988 household in 21 villages as of 2005 (Collinson 2010). Owing to its history as a former Apartheid Bantustan, or black South African "homeland," the Agincourt study site is extremely poor with high population densities, limited service infrastructure, and narrow job opportunities (Goudge et al. 2009; Twine et al. 2007).

Since 1992, the Agincourt HDSS has conducted an annual census of all households in the study site (Tollman et al. 1999). During each census round, a trained fieldworker visits the household unit and interviews the most knowledgeable respondent available to update the household roster. In this way, it is possible to record new births, deaths, in-migrations and out-migrations for each household each year. Data quality checks include duplicate surveying of a random sample of households and rigorous checking of census forms at field and office levels.

Every two or three years, topical modules explore specific policy-relevant areas in more depth. Agincourt HDSS staff fielded a food security module in 2004, 2007, and 2010, which provides the core data for the present analyses. Additional modules provide valuable information regarding factors that influence changes in food security over time, including background on education level, migration, and labor status of household members, in addition to social grants and assets at the household-scale (Collinson 2010).

Multiple imputation Food security data were available across all three years for 8,147 households (68 % of the 11,988 households in the study site), although data were missing for some variables of interest, including household head's employment status (4 % missing), migrant status (3 % missing) and household average educational level (2 % missing).

Given these missing data, conventional modeling approaches that use listwise deletion techniques would substantially reduce the sample size. In addition, error handling methods, such as listwise deletion, use of dummy variables, or mean replacement may produce biased and inefficient inferences, standard errors, and confidence intervals (Little and Rubin 2002; Honaker and King 2010). As such, we chose to employ Multiple Imputation (MI) (Allison 2002; Rubin 1987). The R package "Amelia 2" (Honaker et al. 2011) was used for the missing data imputation because of its capability to process longitudinal data. We imputed five data sets, a sufficient number to obtain robust estimates (King et al. 2001), and ran the regression models on each of the five data sets. Subsequently, the model outputs (e.g., coefficients, standard errors, BIC statistic) were combined using conventional approaches described in the relevant literature (c.f., Nawrotzki 2012; King et al. 2001).

Measures

Outcome variable The household served as our unit of analysis because food security, as a livelihood outcome, best characterizes households, as opposed to specific individuals within the household (Ellis 1998; Devereux and Maxwell 2001; Kirkland et al. 2013). To measure changes in household food security over time, we focused on one specific question: "How often in the last month did your household NOT have enough to eat?" Offered answers included: *never* (= 4), *rarely* (= 3), *sometimes* (= 2), *often* (= 1) and *very often* (= 0) (AHDSS 2009). We observed a slight increase in the mean value of food security across the study years from 3.11 (in 2004) to 3.65 (in 2010). Table 1 provides summary statistics.

Predictor variables To measure change in food security across the study period (2004 to 2010), we included a measure for time in years (respective values: 0, 3, 6) as our main predictor (not shown in Table 1). In addition to investigating overall changes in food security before, during and after the 2008 food security crisis (Hadley et al. 2011), we examined whether these changes differed across groups. Informed by the SL framework, we included socio-demographic characteristics as time invariant predictors, reflecting household conditions as of 2004, or closest to this year when data were collected at different times (e.g., education data collected in 2006; assets data collected in 2003; child grant data collected in 2005). We considered household characteristics as time-invariant predictors to purify our results from the biasing effect of changes in group composition.

Human capital To capture human capital, we used three measures: household level education, working proportion, and

Table 1 Summary statistics of outcome and predictor variables for analyzing changes in food security among various sub populations

Variable	Year	Mean	Std.Dev.	Min	Max
Outcome variable					
Food security	2004	3.11	1.26	0	4
Food security	2007	3.64	0.91	0	4
Food security	2010	3.65	0.92	0	4
Predictor variables					
Human capital					
Average education	2004	5.12	2.51	0	13
Fraction working	2004	0.22	0.19	−0.02	1
Prime age death	2004	0.07	0.25	0	1
Financial & Physical capital					
Wealth index	2004	2.2	0.47	0.94	3.84
Child grants	2004	0.87	1.17	0	11
Social capital					
Head migrant	2004	0.36	0.47	0	1
Head refugee	2004	0.29	0.45	0	1
Natural capital					
NDVI	2004	0.17	0.12	0.05	1.53
Demographic characteristics					
Fraction children	2004	0.34	0.2	0	1
Fraction elderly	2004	0.07	0.16	0	1
Female head	2004	0.38	0.48	0	1

Only the outcome variable was measured as a time series for the three time steps (2004, 2007, and 2010). All predictor variables were included as time invariant and measured at the base year (2004) only. Sample size (n)=8,147 households for which data were available for all three years prime age death. We computed household-level education (sample average [μ]=5 years) as the sum of years of schooling of all household members, adjusted for the household size, while another measure reflects the percentage of household members (μ=22 %) currently working (c.f., Nawrotzki et al. 2013). Following Hunter et al. (2013), we constructed a dummy variable to capture a household's experience of a prime age (15–49 years) death in the prior three years, leading up to the year 2004 (μ=7 %).

Physical and financial capital To account for wealth differences, both in terms of financial and physical capital, we employed a composite measure in line with prior research (Hadley et al. 2011; Mberu 2006; Nawrotzki et al. 2012). Agincourt HDSS constructed and released the wealth index (μ=2.2, range 0.9 to 3.8). The wealth items reflected five broad groups: the availability and quality of modern assets (e.g., TV, car, fridge), livestock assets (e.g., number of pigs or goats), power supply (e.g., use of electricity vs. charcoal), water and sanitation (e.g., type of toilet facility), and characteristics of the dwelling structure (e.g., type of roof material) (see AHDSS 2009, for a detailed description of the scale construction). Child grants served as the only form of social grant available for analyses. We measured the number of child grants per household that received payment (μ=0.87, range 0 to 11).

Social capital As discussed within the SL framework, social capital differs substantially across groups of different residential status, viz. migrants and refugees (Collinson 2010). We constructed dummy variables, reflecting whether a former Mozambique refugee (yes=1; no=0; μ=29 %) or a temporary migrant (yes=1, no=0, μ=36 %) headed a particular household (c.f., Hunter et al. 2013).

Natural capital To approximate access to natural resources, we employed the Normalized Difference Vegetation Index (NDVI) (Tucker 1979), calculated from satellite-based images from MODIS/Terra sensor. Higher NDVI values indicate higher density of vegetation cover and biomass production (Foody et al. 2001; Wang et al. 2004). Other scholars frequently use NDVI as a proxy for access to natural resources (c.f., Hunter et al. 2013; Nawrotzki et al. 2012). Each household in Agincourt is geo-referenced, which allows for computation of household-specific access to natural resources. To this end, we closely followed the methodology described by Leyk et al. (2012): first, we calculated yearly NDVI values by taking the annual mean of 16-day composites from MODIS satellite imagery (250 m resolution); from the NDVI grids, areas within village boundaries were excluded to restrict our measure of natural resources to communal land (e.g., plots within village boundaries are privately owned and not available for resource collection to others than the owners); in the second step, two kilometer buffer zones were generated around each household; the sum of NDVI values within each buffer zone was then computed and divided by the number of households within the buffer to account for varying numbers of households accessing natural resources on communal lands. We chose the size of the buffer based on reports suggesting that households within the Agincourt area usually travel less than two kilometers to access natural resources (Fisher et al. 2012; Giannecchini et al. 2007). To limit the influence of short term fluctuations, we computed the NDVI measure as a three year average leading up to 2004 (c.f., Leyk et al. 2012). Figure 2 shows NDVI values across the Agincourt study site.

Demographic characteristics To capture the impact of the demographic composition, such as age structure of households, we computed the percentage of household members below age 15 (μ=34 %) and the percentage age 65 and above (μ=7 %). To capture gender differences, a dummy variable indicated the sex of the household head (female=1; male=0; μ=38 %).

Statistical modeling approach

The AHDSS panel data set allows for a longitudinal, multilevel model design, also known as growth modeling (c.f., Curran and Bauer 2011; Singer and Willett 2003), to investigate temporal changes in food security. Growth models are well suited for our analysis, because they automatically correct the standard errors of the fixed part for the degree of dependence in the repeated measures, and thereby, protect against type I errors.

We first estimated an unconditional means model (Eq. 1, Table 2, Model 1), as recommended by Singer and Willet (2003:75), to compute the intra class correlation coefficient (ICC), suggesting that differences across households explains 7 % of the variance in food security. Using a linear growth model, we regress the conventional intercept β_0, on the dependent variable, food security (*FS*). The household-level random intercept u_{0i} represents the variation in the average level of food security across households (n=8,147). The random intercept term is normally distributed with variances σ^2, quantifying the between-households variation. The parameter r_{ti} represents the time and household specific error.

$$FS_{ti} = \beta_0 + u_{0i} + r_{ti} \quad (1)$$

In the second step (Eq. 2, Table 2, Model 2), we include a measure of time that centered on the starting value of the time series (year 2004). In this equation, the coefficient β_1

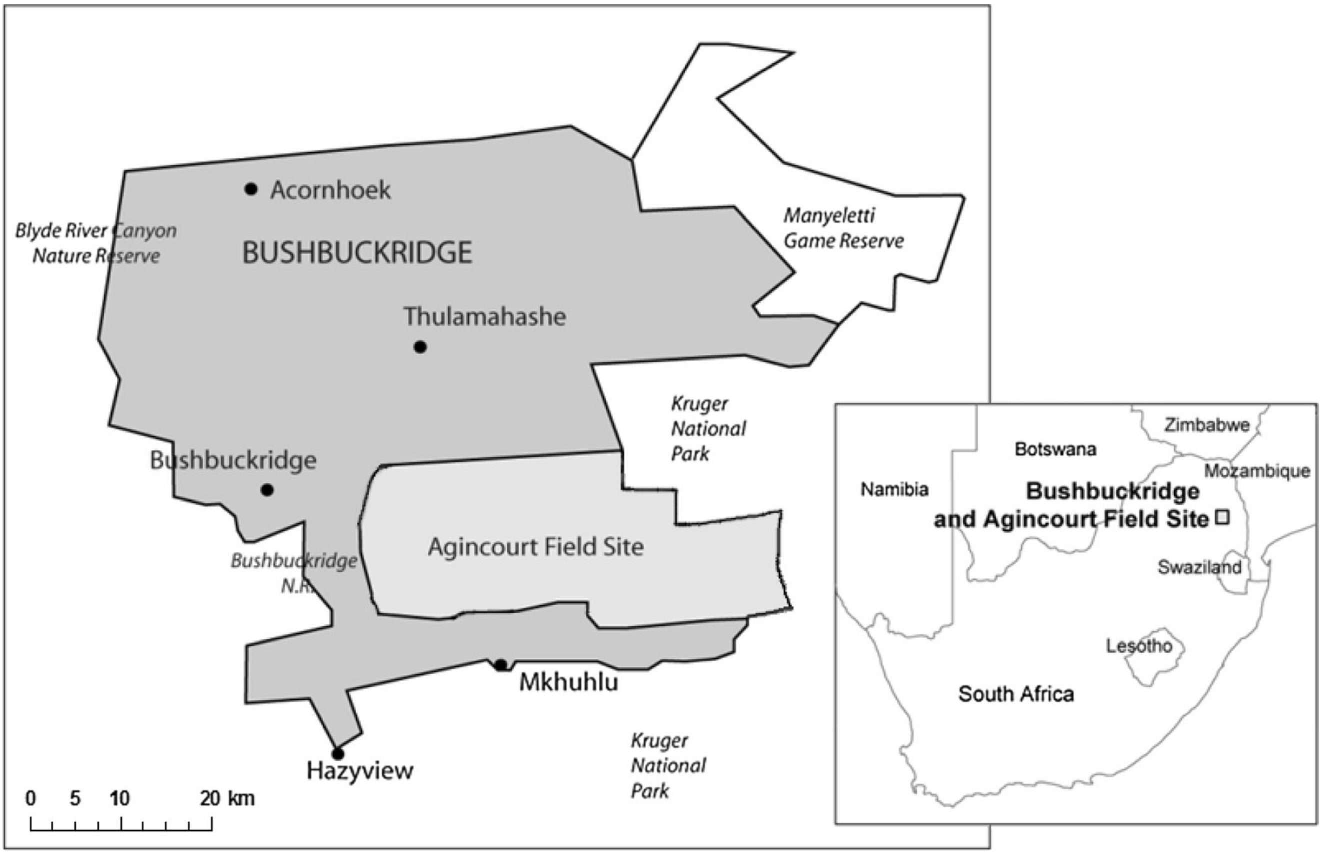


Fig. 1 Agincourt Health and Demographic Surveillance site located south east of Kruger National park. Source: Hunter et al. (2013)

represents the within-household trajectory of time and operates at level-1.

$$FS_{ti} = \beta_0 + \beta_1(time_{ti}) + u_{0i} + u_{1i}(time_{ti}) + r_{ti} \tag{2}$$

In addition to the intercept (u_{0i}), the slope of time (u_{1i}) can randomly vary across households, demonstrating an important feature of the growth model; some households might have higher initial levels of food security than others, and some households may experience a more rapid change in food security than their neighbors.

We modified the predictor for time by including a second order polynomial that allowed us to approximate a non-linear trajectory of changes in food security over the study period (Eq. 3, Table 2, Model 3). The regression coefficients β_1 and β_2 allow us to investigate our first research question: *Has food security among households in rural South Africa changed between 2004 and 2010?*

$$FS_{ti} = \beta_0 + \beta_1(time_{ti}) + \beta_2(time\ sq._{ti}) + u_{0i} + u_{1i}(time_{ti}) + u_{2i}(time\ sq._{ti}) + r_{ti} \tag{3}$$

As Eq. 3 shows, we included an additional random slope parameter (u_{2i}) to allow the shape of the curve for time and the inflection point to vary across households. Assuming a joint normal distribution, the three random effects have the following variance-covariance structure (Eq. 4).

$$\Omega_u \sim N\left(0, \begin{bmatrix} \sigma^2_{u0} & & \\ \sigma_{u0u1} & \sigma^2_{u1} & \\ \sigma_{u0u2} & \sigma_{u1u2} & \sigma^2_{u2} \end{bmatrix}\right) \tag{4}$$

We expanded the model further by including time-invariant covariates (Eq. 5, Table 2, Model 4) that vary only across households (e.g., average education, percent working, female head, etc.) and not within households (e.g., same value for all years). These enter the model at level-2 (denoted by a single $_i$ subscript). Eq. 5 illustrates the inclusion of a time invariant predictor using the female headship variable as example. The parameter β_3 reflects the expected change in average value of food security (intercept), comparing female- to male-headed households.

$$FS_{ti} = \beta_0 + \beta_1(time_{ti}) + \beta_2(time\ sq._{ti}) + \beta_3(female\ head_i) + u_{0i} + u_{1i}(time_{ti}) + u_{2i}(time\ sq._{ti}) + r_{ti} \tag{5}$$

However, to answer our second research question (*Do changes in the food security situation differ for marginalized*

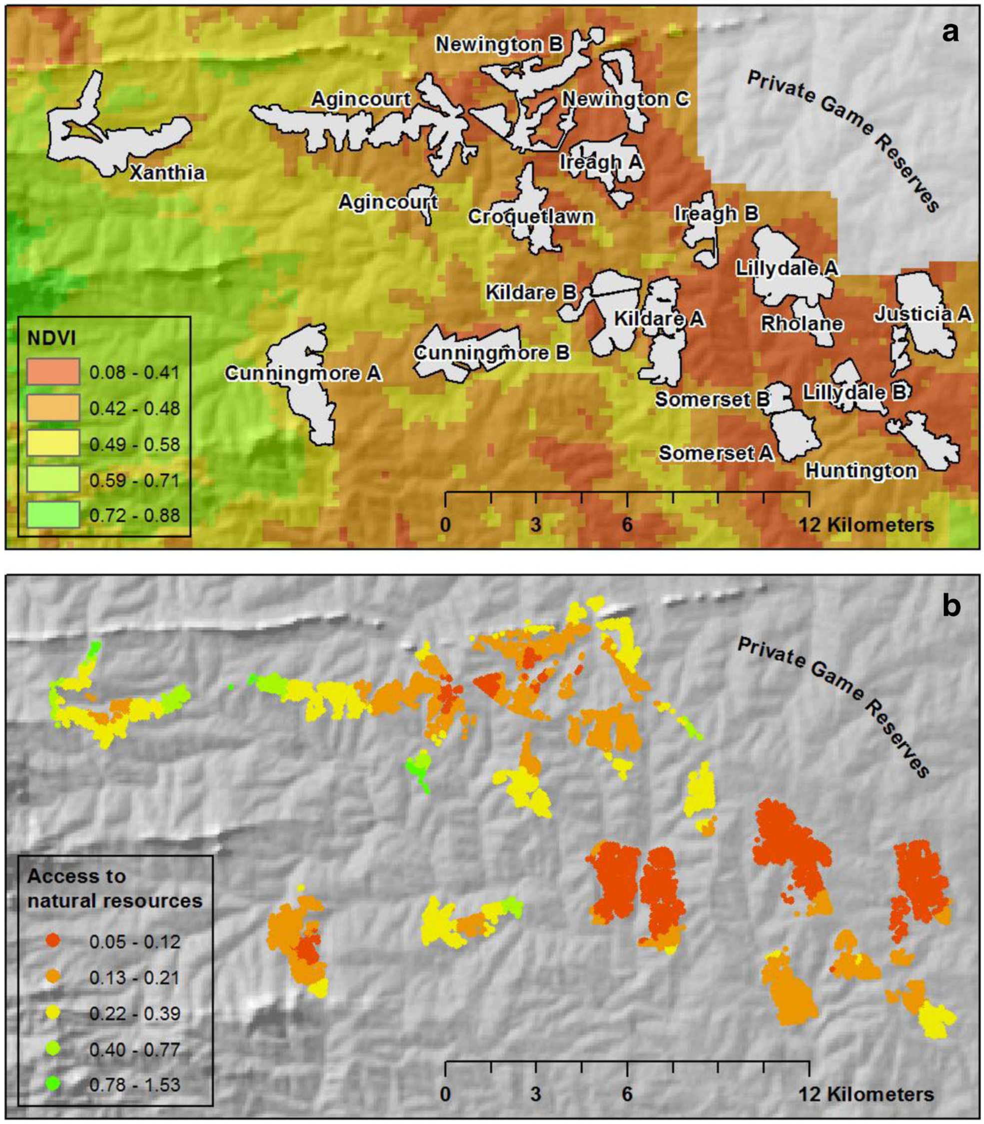


Fig. 2 Mean NDVI values averaged across the 3 year period leading up to the year 2004 for the Agincourt study site. Note: Panel (**a**) shows the average NDVI values (2002–2004) for the study region; Panel (**b**) shows the population weighted access to natural capital per household. Topography is visualized using a digital elevation model (DEM)

populations?), we made use of cross-level interactions between time, time squared, and the time-invariant covariate (Eq. 6, Table 3).

$$FS_{ti} = \beta_0 + \beta_1(time_{ti}) + \beta_2(time\ \ sq._{ti}) + \beta_3(female\ \ head_i) + \beta_4(time_{ti} * female\ \ head_i) + \beta_5(time\ \ sq._{ti} * female\ \ head_i) + u_{0i} + u_{1i}(time_{ti}) + u_{2i}(time\ \ sq._{ti}) + r_{ti} \quad (6)$$

If in Eq. 6, both β_4 and β_5 prove significant; then, the change in food security over time differs for female, compared to male households. We used the *lme4* package (Bates 2010) within the "R" statistical environment version 3.0.1 (R Core Team 2013) to fit the growth models.

Results

Additive models

We observed an overall improvement in food security in Agincourt across the study period (see Table 2). However, this increase is nonlinear, characterized by a positive deceleration in the growth curve. The improvement in food security begins strongly and then levels off, as can be inferred from a negative coefficient for the squared term for time (b=−0.03; $p<.001$). In June 2008, the curve reached the inflection point (inflection point=$-\beta_1/(2*\beta_2)$). Including a second order polynomial of time, strongly improves the model fit, as evidenced by a reduction in the BIC statistic by 906 points. Figure 3 visualizes the change in food security across time and illustrates the substantial variation in food security trajectories, using 20 randomly chosen households as examples.

Table 2 Additive growth curve models for the investigation of changes in food security across the time period of 2004 to 2010 in Agincourt

	Model 1		Model 2		Model 3		Model 4	
	b	sig.	b	sig.	b	sig.	b	sig.
Variables								
Intercept	3.47	***	3.2	***	3.11	***	2.27	***
Time			0.09	***	0.27	***	0.27	***
Time sq.					−0.03	***	−0.03	***
Average education							0.02	***
Fraction working							0.34	***
Prime age death							−0.06	*
Wealth index							0.26	***
Child grants							−0.01	*
Head migrant							0.09	***
Head refugee							0.01	
NDVI							−0.19	**
Fraction children							0.16	***
Fraction elderly							0.54	***
Female head							−0.05	**
Model statistics								
Residual variance	1.074		0.890		0.747		0.742	
Variance Intercept	0.079		0.493		0.844		0.780	
Variance slope (Time)			0.012		0.178		0.181	
Variance slope (Time sq.)					0.002		0.002	
BIC	72756		71000		70094		69481	
N	24441		24441		24441		24441	

BIC Bayesian Information Criterion with lower values indicating better model fit. Low variance inflation factor (VIF) values indicate that multicollinearity does not bias the estimates. Significance levels: *=$p \leq 0.05$; **=$p \leq 0.01$; ***=$p \leq 0.001$

The secondary predictors behave largely as expected, based on findings of prior studies (Model 4, Table 2). The strongest protective factors with regard to food security in 2004, our base year, included: a high level of education, a high percentage of working household members, and the possession of various physical assets (wealth index). In addition, migrant-headed households and those with a higher proportion of dependent members (e.g., elderly and children) proved to be more food secure. In contrast, those most insecure in 2004 with regard to food had experienced the death of a prime age adult member, were living in areas with better access to natural resources, were female headed, and were poor enough to qualify for receiving child grants.

Interaction models

To investigate changes in food security for vulnerable groups, we employed cross-level interactions. Interacting all secondary predictors with the time variables revealed systematic differences in the changes in food security (see Table 3).

Table 3 demonstrates significant differences in food security trajectories for households characterized by: different proportions of working members, receipt of child grants, migrant status, and refugee status. In addition, access to natural resources, the proportion of elderly members within a household, as well as the gender of the household head shaped changes in food security over time. A set of graphs facilitates the interpretation of the interaction terms (Figs. 4 and 5).

Figure 4 demonstrates improvements in food security between 2004 and 2010 for households with low proportions of working members. Among households receiving child grants, food security improved less, compared to those who did not receive child grants. While households headed by a migrant had initially higher levels of food security, non-migrant households caught up around 2006, and slightly surpassed migrant households by the end of 2010. Mozambique refugee households, instead, saw a deterioration of their food security status across the 6 year study period. Although the absolute decline in livelihood security for refugees was small, the relative gap between refugees and non-refugees widened substantially between 2004 and 2010.

Figure 5 shows that access to natural resources positively impacted changes in food security. Although households with

Table 3 Cross-level interaction models for the investigation of differential changes in food security for vulnerable sub populations across the time period of 2004 to 2010 in Agincourt

	Model 1		Model 2		Model 3		Model 4	
	b	sig.	b	sig.	b	sig.	b	sig.
Variables								
Intercept	2.15	***	2.26	***	2.22	***	2.24	***
Time	0.33	***	0.28	***	0.29	***	0.30	***
Time sq.	−0.03	***	−0.03	***	−0.03	***	−0.03	***
Fraction working	0.89	***	0.34	***	0.34	***	0.34	***
Child grants	−0.01	*	0.00		−0.01	*	−0.01	*
Head migrant	0.09	***	0.09	***	0.22	***	0.09	***
Head refugee	0.01		0.01		0.01		0.12	***
Time x fraction working	−0.28	***						
Time sq. x fraction working	0.02	***						
Time x Child grants			−0.02	*				
Time sq. x Child grants			0.00	*				
Time x Head migrant					−0.07	***		
Time sq. x Head migrant					0.01	*		
Time x Head refugee							−0.11	***
Time sq. x Head refugee							0.02	***
	Model 5		Model 6		Model 7			
	b	sig.	b	sig.	b	sig.		
Variables								
Intercept	2.35	***	2.25	***	2.29	***		
Time	0.20	***	0.28	***	0.24	***		
Time sq.	−0.02	***	−0.03	***	−0.03	***		
NDVI	−0.67	***	−0.19	**	−0.19	**		
Fraction elderly	0.54	***	0.81	***	0.54	***		
Female head	−0.05	**	−0.05	**	−0.12	***		
Time x NDVI	0.39	***						
Time sq. x NDVI	−0.05	***						
Time x fraction elderly			−0.20	**				
Time sq. x fraction elderly			0.02	**				
Time x Female head					0.07	***		
Time sq. x Female head					−0.01	**		

All models were fitted with the complete set of covariates used in Model 4, Table 2. The display of coefficients of control variables and variance components was omitted to preserve space. Significance levels: *= $p \leq 0.05$; **= $p \leq 0.01$; ***= $p \leq 0.001$

the best access to natural resources were initially less food secure, these households improved in food security over time and surpassed those households with lower levels of access to natural resources in 2010. We observed only small differences in the food security trajectory between households with different proportions of elderly members. While those households with higher proportions of elderly were initially more food secure, this advantage diminished over time. Finally, positive changes for female-headed households became evident. This vulnerable subgroup began with a low level of food security compared to their male headed counterparts. However, female head's improvements were stronger, resulting in a better food security situation by 2010.

Discussion

In this study, we sought to investigate changes in food security among residents of a longstanding demographic surveillance site in rural South Africa during the time of the global food security crisis of 2008. We employed additive, random slope models to answer our first research question: *Has food security among households in rural South Africa changed between 2004 and 2010?* Overall, the observed trend reflects the global changes in food security remarkably well, with an increase in food security until the onset of the global food security crisis during 2008 and leveling off thereafter (FAO, WFP, and IFAD 2012). In contrast to other African countries, such as Ethiopia (e.g., Hadley et al.

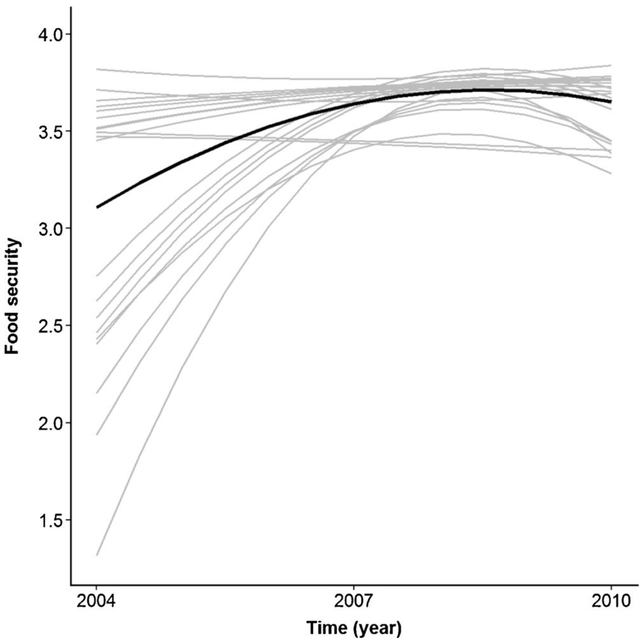


Fig. 3 Adjusted growth curve of change in food security over time. Note: Thin *grey lines* reflect the change in food security over time for 20 randomly chosen households. The thick black line shows the average trajectory of food security derived from the regression parameters of Model 4, Table 2

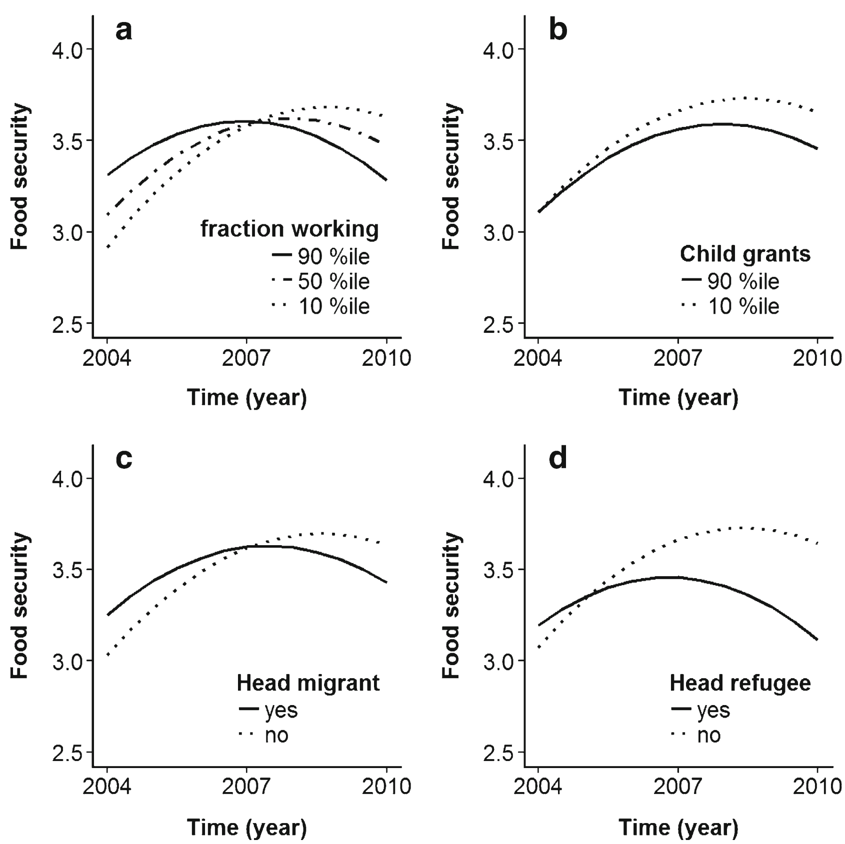
2011), we did not observe a decline in food security between 2004 and 2008, most likely due to South Africa's comparatively strong economic conditions and a well-functioning social security system (Twine et al. 2007; Wheeler and von Braun 2013, Fig. 1).

In response to our second research question (*Do changes in the food security situation differ for marginalized populations?*), we employed cross-level interaction models. The findings revealed that most disadvantaged sub-populations in the Agincourt study site fared comparatively well during the time of the global food security crisis.

An increase in the size of the payment of social grants, such as disability or old age pensions, helps to explain some of the findings (ODI 2006). For example, having a disabled adult household member may lead to a lower employment ratio, but better access to disability grants and higher payments might have differentially increased the food security level of this subgroup. In addition, individuals in households receiving social grants increase their labor force participation and employment rates faster than those who live in households that do not receive social grants (Samson et al. 2004).

Similarly, higher levels of old age pension receipt explain the positive improvement in food security among female headed households (Schatz et al. 2012). During the study period, women were eligible to receive old age pensions at an earlier age (age 60), compared to men (age 65) (ODI 2006). Due to the earlier pension eligibility and longer life expectancy, more women receive pensions in South Africa than men (Burns et al. 2005). In our data, female household heads were, on average, five years older (54.0 years) compared to male heads (48.7). As such,

Fig. 4 Visualization of variation in food security trajectories for different sub populations defined by percentage of household members working (**a**), receipt of child grant benefits (**b**), migrant status of the household head (**c**), and refugee status of the household head (**d**)



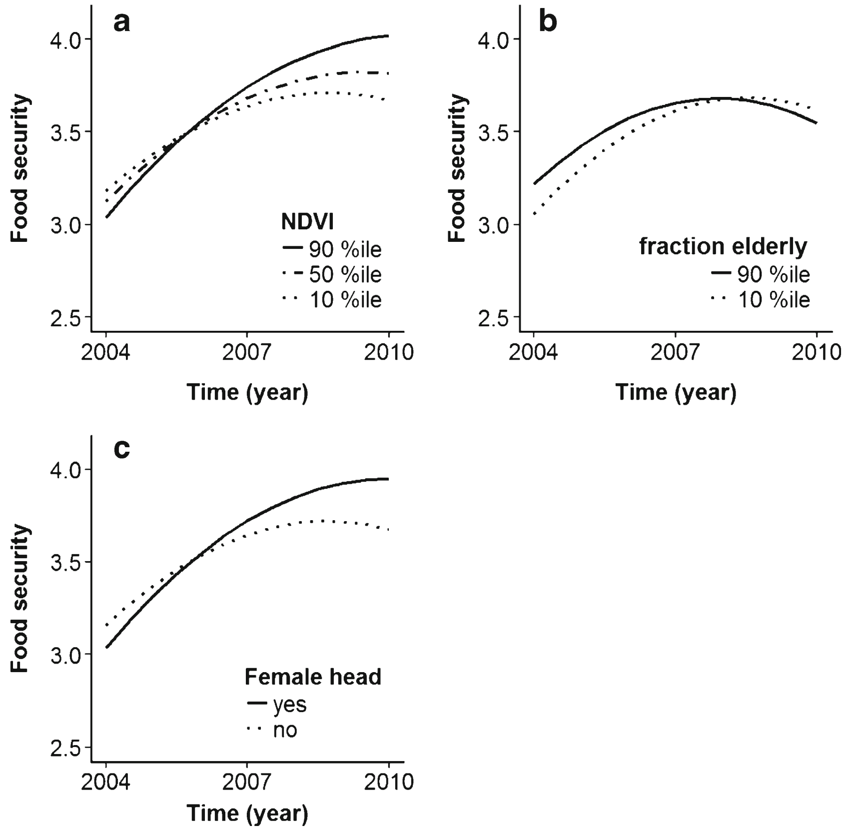


Fig. 5 Visualization of variation in food security trajectories for different sub populations defined by access to natural resources (**a**), percentage of elderly in the household (**b**), and gender of the household head (**c**)

female headed households might have benefitted particularly from an increase in the amount paid for old age pension over the study period. However, having a greater number of elderly in the household does not necessarily lead to improvements in food security, as Fig. 5, Panel b shows.

Although, they were able to improve their food security situation over time, households receiving child grants performed lower, compared to households that did not receive child grants, which might be related to the overall low socio-economic status of households qualifying for child grant support. The food security crisis disproportionately impacted the poorest of the poor (Compton et al. 2010), and our findings support this point.

Also, migrant households lost their comparative advantage over time. Labor migrants working in the surrounding industrial areas or mines use their income to purchase food and do not spend much time and resources on food production and farming, which makes them net consumers. Under conditions of rising food prices, these net consumer households spend a higher percentage of their total budget on purchasing food, whereas households without a migrant are likely to rely more heavily on local food production and natural resource collection, making them less vulnerable to the impacts of rising food prices (Hadley et al. 2011).

This effect also explains why we observed a differential improvement in food security among households residing in areas with better access to natural resources. We can assume that these households are more likely to use the available natural capital. Although these households tended to be more food insecure prior to 2008, they differentially improved their food security during the time of the crisis, perhaps due to the reliance on local food production instead of purchases. In line with prior research in the study site (Hunter et al. 2007), these findings stress the importance of natural resources for food security in times of crisis.

Finally, our findings reveal that former Mozambique refugees were hit hardest by the 2008 food crisis. A combination of social stigmatization, low socioeconomic status, and lower access to social grants likely caused the decline in food security. Other studies found that former Mozambican refugee households possessed significantly lower levels of access to social grants, compared to South African natives, due to a lack of necessary documentation and issues of proper residential status (Twine et al. 2007; Schatz 2009).

Based on these findings, we recommend the development and implementation of programs to improve the food security situation among former Mozambican refugee households. Perhaps the most effective intervention might relate to extending social grants to former Mozambicans. This requires further assistance to obtain official documentation, such as birth certificates, which are necessary to access grants.

Although carefully conducted, this study has limitations. First, having only three years of food security data available, limits the analysis. Different growth curve trajectories may become apparent with more data points. Second, the availability of variables posed some limitations to our analysis. For example, a measure of the reception of old age pension would have been helpful to confirm our explanation regarding the interaction between working proportion, migrant status, refugee status and time. Similarly, our measures of social capital (e.g., migrant and refugee status) can only serve as rough approximations. Future studies should include measures of network densities, kinship ties, and social isolation to better account for the beneficial impact of these connections on food security (c.f., Hadley et al. 2011). Third, our data set does not allow for the construction of a valid multi-item scale of the experience of hunger. However, using a single-item measure facilitates the substantive interpretation of the effects, and Keenan et al. (2001) have demonstrated the validity of single-item measures for the investigation of food security. In addition, Kirkland et al. (2013, p.77) recently showed that various measures of experience of hunger "have significant overlap in identifying food insecure households" in the Agincourt HDSS study site. An additional limitation of our dependent variable is that it constitutes a subjective indicator of food security. Future research might triangulate the observed findings through the use of objectively measurable bio-physical indicators of food security such as Body Mass Index (BMI) or nutrition intake schedules.

Despite these limitations, we trust that this research contributes to the literature by investigating changes in food security among vulnerable sub-populations in rural South Africa during the 2008 global food crisis.

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