

Climate Change and Human Health: Multilevel Modeling of Climate, Livelihoods, and Population Change for Child Malnutrition in Mali, Africa

Working Paper (preliminary results)

Background

Climate change will have far reaching consequences for sub-Saharan Africa in the near future, particularly in the realm of health and malnutrition. As a significant portion of the population in the region derives its livelihoods from agriculture, changes in precipitation and temperature patterns will likely increase migration and vulnerability, all while significantly impacting food security and malnutrition (Cohen et al., 2008). More than 200 million people are malnourished in sub-Saharan African countries, and this number could grow by 12 million as temperatures rise and crop yields fall (McMichael et al., 2008). Almost all research concerning the effects of climate change on malnutrition points to a worsening situation in the coming years (McMichael, 2001; WHO, 2002; Patz et al., 2005; Legg, 2008; Obersteiner et al., 2010). Children, an especially vulnerable group, are at the greatest risk of increased suffering from malnutrition driven by climate change (Shea & The Committee on Environmental Health, 2007; UNICEF, 2008).

The complex system of changes that is sparked by climate change and results in child malnutrition is excessively difficult to model – statistically defensible links have only been established by a handful of studies drought (Maleta et al., 2003; Singh et al., 2006; Jankowska and López-Carr et al., 2011). Climate change impacts on malnutrition are difficult to capture and quantify, because they are diffused through a multitude of macrosocial factors (Sheffield & Landrigan, 2011). Additionally, they are constantly changing as climate change alters the current physical and social landscape – forcing changes in livelihoods, adaptation strategies, economies, and migration patterns. In a previous paper, we linked climate change to negative stunting outcomes, even when controlling for livelihoods (Jankowska and López-Carr et al., 2011). This paper attempts to fill in and better understand the story by utilizing a multilevel model to examine the hierarchical structure of the global processes of climate and demographic change as they work through regional livelihood structures to influence individual level malnutrition outcomes in Mali, Africa.

Climate and Malnutrition

Chronic malnutrition is already a pressing concern resulting in stunting among a third of all children under five years of age born in developing countries, and climate change is expected to further reduce food security in these areas (Costello et al., 2009). Llyod et al. (2011) project that by 2050 climate change will result in a 1-29% increase in moderate stunting, and a 23% increase in severe stunting in children in sub-Saharan Africa. The effects of childhood malnutrition, even as the result of a temporary environmental or economic change, can linger for decades. Malnutrition may result in impaired health and development, limited learning capacity, impaired immune systems, reduced adult work performance and productivity over the life-course, and an increased chances of giving birth to undernourished babies (ACC/SCN and IFPRI, 2000; Cohen et al., 2008; Alderman, 2010). Malnourished children are much more susceptible to other diseases, much less likely to recover from an illness when it does strike, and are more likely to be weakened as adults (Akachi et al., 2009).

Malnutrition is a significant problem for Mali, and projected increases of hunger risks could have catastrophic impacts on the population's health and economic productivity. The 2006

Demographic and Health Survey (DHS) found that 60% of children aged 6 to 59 months are moderately or severely anemic, while 50% of children 18 to 23 months are stunted and 25% are underweight (DHS, 2007). Overall, acute malnutrition affects 15% of children less than five years old as measured by World Health Organization standards. In the only extensive study on climate and health in Mali, Butt et al. (2005) found crop yield changes by 2050 will range from minus 17 to plus 6% at the national level, forage yields will fall by 5 to 36%, and livestock animal weights will be reduced by 14 to 16%. In terms of health, they project that climate change will increase the proportion of the country's population at risk of hunger from 34% in 2005 to 64-72% in the 2050s, unless adaptation measures are successfully implemented (Butt et al., 2005).

Research concerning child malnutrition has recently begun to include community and regional factors that may influence malnutrition using hierarchical modeling structures to examine urban/rural, program, community, and country level differences and effects (Fotso & Kuate-Defo, 2005; Fotso, 2007; Rajaram et al., 2007; Uthman, 2009). These studies generally find that while individual and household level factors are the most important aspects of malnutrition, the larger context that a child lives in plays an important role for risk. They also demonstrate the utility of modeling malnutrition using a hierarchy of effects: the approach can capture layers of malnutrition drivers as they make their way down from global forces to the individual child. However, the inclusion of climate or demographic change in a multilevel model of child malnutrition has not been attempted to our knowledge.

Livelihoods and Demographic Change

Livelihoods are a way of understanding food economies as represented by a typical rural household's everyday circumstances and ability to obtain access to food (Boudreau, 1998). A household's livelihood dictates food access and availability, and is the primary interface between nutrition and climate change (Bloem et al., 2010). Unstable agricultural systems drive food insecurity, and societies with insecure food supplies are more susceptible to shocks in agricultural productivity (Haines & McMichael, 1997; Alderman, 2010; Darnton-Hill & Cogill, 2010). These shocks degrade income and livelihoods, because many farmers in food insecure regions grow crops to consume and sell, decreasing yield impacts both household incomes as well as nutritional well being (Brown & Funk, 2008). The inability to protect the household against shocks has adverse consequences across generations through reduced investment in nutrition, health, and schooling (Alderman, 2010). A conceptual understanding of livelihoods, interfaced with climate-based variables to analyze the potential for exposure to particular hazards, permits the assessment of both risk and adaptation potential by livelihood zone (Verdin et al., 2005).

Demographic processes, particularly migration, are alternative or additional adaptation strategies. A decline in crop yields across climate vulnerable regions of sub-Saharan Africa results in considerable numbers of environmentally-induced migrants (Swain, 1996; Adepoju, 2003). Little research exists on migration promoted by gradual environmental change (Findlay & Hoy, 2000; Mortreux & Barnett, 2009), nor on the exposures these migrants face in their new homes. However, migrants will likely add to agricultural pressure, and when actively caused by climate change will compound local vulnerabilities, degradation of resources, and economic stressors. Another aspect of demographic change is natural growth. The population growth rate of sub-Saharan Africa, while stabilizing, is still on the rise particularly in rural areas. Larger populations will place more stress on food systems, and in turn may increase risk of malnutrition.

This paper will explore relationships between temperature, precipitation, livelihoods, demographics, and child malnutrition using the US Agency for International Development's

Famine Early Warning System Network (FEWS NET) climate models, FEWS-NET livelihood classifications, Afripop high resolution demographic data and projections, and Demographic and Health Survey (DHS) malnutrition data. The goal is to understand the hierarchical nature of impacts on malnutrition beginning with the individual and moving outward to the cluster and region. We are not aware of any multilevel studies examining the effects of demographic and climatic change on child malnutrition, thus this paper will add a novel contribution to the demographic, health, and climate change literatures.

Data and Methods

At present, climate trend estimates are typically presented without accounting for the spatial accuracy of the estimation procedures. The method utilized for this research attempts to rectify this inadequacy by using an approach supported by USAID FEWS NET, with long term mean field projections dubbed FEWS NET Climatology (FCLIM). FCLIM rainfall projections incorporate climate, satellite, and physiographic data using a total of ten specific input variables including station observations, satellite observations, and physiographic predictors. Instead of focusing on the ability of datasets to represent *temporal* variations in weather, the FCLIM approach focuses on the ability of these variables to represent *spatial* gradients of temperature and precipitation. While any climate projection is fraught with uncertainty, for short term (~20 year) projections, this approach may be the best available given the current state of climate science. A full description of the FCLIM procedure can be found in Jankowska and López-Carr et al. (2011). The resulting measure from the FCLIM procedure is a water balance index that is indicative of how much moisture soil can retain labeled PPET, where positive values represent wet areas and negative values are regions where atmospheric water demand exceeds the rainfall supply (Figure 1).

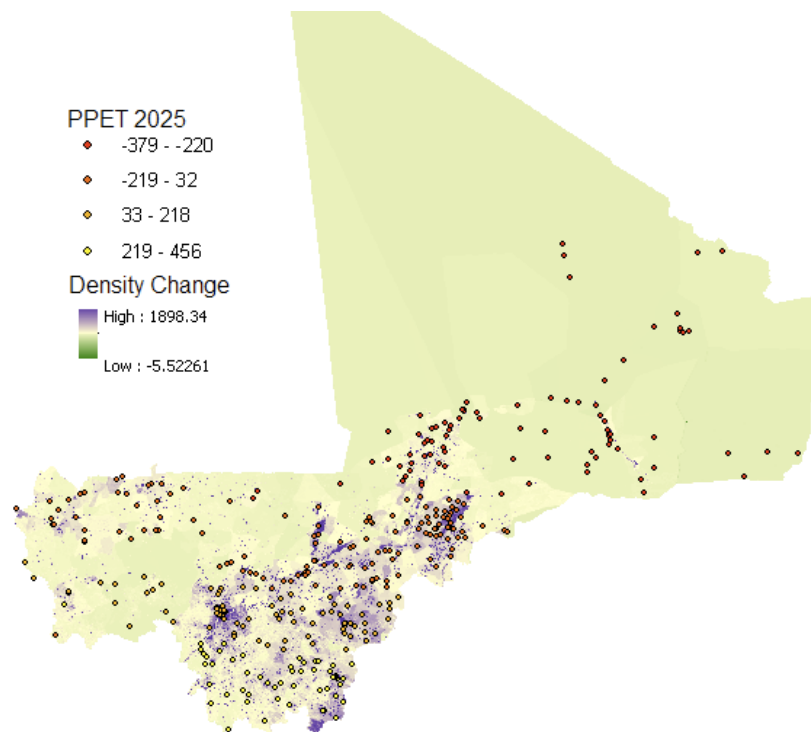


Figure 1. Change in population density (ppl per 1 square kilometer) from 2000 to 2015 in Mali. Dots are representative of 2006 DHS cluster locations, as well as the PPET gradient throughout the country, which moves from hot/dry in the north-east, to cool/wet in the south-west.

Population change for Mali (Figure 1) is derived from the AfriPop project (http://www.clas.ufl.edu/users/atatem/index_files/AfriPop.htm), which provides fine scale gridded population estimates for all of Africa for years 2000 to 2015 (Tatem et al., 2007; Tatem & Linard, 2011). Data created by AfriPop is derived from recent censuses, census microdata, household surveys, as well as high resolution satellite imagery interpretation and georeferencing. Projections to 2010 and 2015 are made using collation of subnational inter-censal growth rates. However, the data does not incorporate potential climate-related migration.

Health data was drawn from the 2006 DHS IV for Mali (DHS, 2007). Increasingly, health researchers are taking advantage of global positioning systems (GPS), which during recent rounds of DHS surveys have provided location attributes of clustered households (Tanser & Le Sueur, 2002). DHS data have been analyzed in hundreds of studies in the public health literature, including those examining human-environmental interactions (Sutherland et al., 2005; De Sherbinin et al., 2008). However the use of DHS cluster data to examine climate effects on humans has not been attempted to our knowledge. The survey sample of 410 clusters was stratified and weighted, and is representative at the national, regional (8 regions plus Bamako, Mali's capital), and residential (urban/rural) levels. A total of 405 clusters were successfully surveyed including 14,238 children (clusters shown in Figure 1). Two commonly utilized measures of nutrition were selected from the DHS for analysis: the child's measure of stunting (height divided by age indicative of chronic malnutrition), and the child's measure of underweight status (weight divided by age indicative of short-term malnutrition). Stunting and underweight are assessed by number of standard deviations from the World Health Organization (WHO) child growth standards, with measures of -2 standard deviations from the guideline considered malnourished (WHO & UNICEF, 2009).

Livelihood zones are utilized from the FEWS NET website (<http://www.fews.net/pages/livelihoods-learning.aspx?l=en>). FEWS NET Livelihoods take into account numerous factors that dictate food economics including agro-ecology (what people can grow or produce and where), assets, expenditures, income, and coping capacities to various vulnerabilities. After accounting for major individual factors, livelihoods should account for much of the variability of measured malnutrition. FEWS NET delineates 13 livelihood zones for Mali. Similar zones were aggregated, resulting in 8 dummy coded regions (Table 1). The pastoral livelihood is characterized by having rainfall less than 200mm, being sparsely populated, and relying on livestock and limited agriculture. People are particularly susceptible to threats to their herds, with limited activities to serve as secondary response strategies. The rice livelihood is dependent on rice production for food, but also includes livestock rearing, as well as some farming. For all of these livelihoods, there is a reliance on water from the Niger River, and its inland delta for water. Coping mechanisms typically involve additional sales of livestock to increase income.

Table 1. Livelihood zones, arid climate zone, and stunting and underweight variable means.

Zone	Description	# DHS Clusters	Stunting \bar{x}	Underweight \bar{x}
Pastoral	Nomadism, trans-Saharan trade, transhumant pastoralism	37	-1.37	-1.19
Rice	Fluvial rice, Niger Delta rice, Irrigated rice, livestock rearing	50	-1.54	-1.39
Plateau	Millet, shallots, wild foods, tourism	27	-1.70	-1.27
Millet	Millet and transhumant livestock rearing	33	-1.51	-1.32

Rainfed Millet	West and central millet/sorghum	68	-1.42	-1.26
South Crops	Sorghum, millet, cotton, maize, fruit	120	-1.57	-1.26
Urban	Bamako – capital city	49	-0.75	-0.86
Remittances/ Livestock	Livestock rearing and significant reliance on remittances	21	-1.25	-1.25

The plateau, millet, and rainfed millet livelihoods highlight the transitional nature of this region from pastoral semi-arid to agricultural livelihoods, as well as from sparse to moderate population density. The millet livelihood zone is characterized as a net importer of staple grains from the southern zones with occasional successful millet production, and livestock as the most valuable product. The rainfed millet livelihood zone dominates grain trade in Mali, with particularly intense exporting to northern areas of the country. Millet remains the major crop of this livelihood zone, however all millet is rainfed, and the rainfed in the title also applies to the production of rainfed sorghum towards the south of the zone as compared to recessional sorghum in the country's deep south. The south crops livelihood has more rain than the other livelihoods and primarily produces maize and cotton.

An individual and then multilevel model in MIWin software is implemented using a hierarchical nested structure of children, within households, within DHS clusters. Of the original 14,238 children included in the survey, 3,512 were removed due to missing data, leaving 10,726. All 405 clusters were included. At the individual level variables concerning the mother (education and age), household members (age of household head, number of household members, number of children under 5 in the household), and household wealth were included as factors that are likely to influence malnutrition at the individual level. At the cluster level the mean cluster wealth, PPET measures from 2000 and 2025, population density change from 2000 to 2015, and livelihood are included. Variables, means, and standard deviations of all variables included in the model are in Table 2.

Table 2. Descriptive statistics for individual and cluster model input variables.

Variable	Description (Individual Level n=10,726)	Mean	Standard Deviation
Stunting	Standard deviations of height/age	-1.429	1.923
Underweight	Standard deviations of weight/age	-1.232	1.389
EducMother	Education of mother in years	0.9	2.48
MothAge	Age of mother	28.44	7.092
HeadAge	Age of household head	41.78	11.757
HNumb	Number of household members	7.41	3.650
Under5	Number of children under 5 years of age in household	2.27	1.179
Wealth	Household wealth index from 1 (poorest) to 5 (richest)	3.00	1.370
Variable	Description (Cluster Level n=405)	Mean	Standard Deviation
Wealth	Mean cluster wealth	3.132	1.119
PPET00	Year 2000 PPET measure at cluster location	-10.786	227.992
PPET25	Year 2025 PPET measure at cluster location	-19.716	219.609
PopChange	Population density change per square kilometer from 2000 to 2015 at cluster location	98.124	210.058
Livelihood	Livelihood that cluster engages in (Table 1)		

At the individual level, an step-wise ordinary least squares regression was run examining individual level effects for both stunting and underweight. Interaction effects were examined for

particularly significant variables. Variance at the individual and cluster level, as well as the variance partitioning quotient (VPC – percentage variance explained by the higher level) was calculated for each model as variables were input. A second level was then introduced at the cluster level, with the wealth, livelihood, PPET, and demographic variables included.

Preliminary Results

Modeling for this paper is still ongoing, however selected preliminary results for the stunting outcome are briefly presented. At the individual level (Table 3), the household wealth and mother’s education have the most influence on stunting, with mother’s age indicating some significance. Figure 2 indicates the directionality of each of the effects, which are to be expected: increasing wealth and mother’s education has a positive impact on stunting, while increasing mother’s age has a negative impact on stunting.

Table 3. Individual level regression results, with level 1 and 2 variances, as well as VPC.

Model	Deviance	Change in deviance	Change in Df	p value	Lev2var	Lev1var	VPC
Base	43920.6	0.000	*	*	0.306	3.424	0.08
Wealth	43814.3	106.299	4	0.000000	0.198	3.427	0.05
EducMother	43861.5	59.049	1	0.000000	0.260	3.419	0.07
MothAge	43915.4	5.151	1	0.023233	0.303	3.424	0.08
HNumb	43919.6	1.013	1	0.314185	0.307	3.424	0.08
Under 5	43920.4	0.166	1	0.683692	0.307	3.424	0.08
HeadAge	43920.5	0.035	1	0.851596	0.307	3.424	0.08

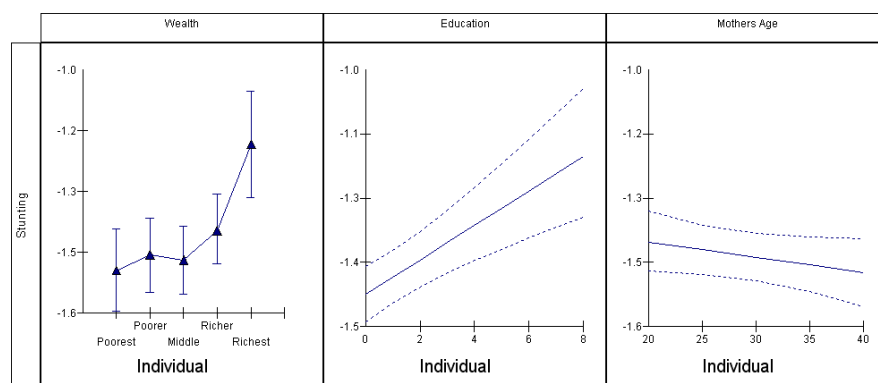


Figure 2. Individual level effects of wealth, mother’s education, and mother’s age on stunting with confidence intervals.

The VPC fluctuates depending on which variables are included in the individual level model, from 5 to 8% of variance explained at the cluster level. This is a sizeable amount of variance that is at the cluster level, indicating significant differences in stunting between clusters. The level 2 variance drops with the introduction of mother’s education, and particularly with the introduction of wealth indicating the importance of wealth, and that there may be cluster level wealth effects as well.

The level two model indicates significant effects of livelihoods, as well as significant effects of livelihood and PPET interactions. Demographic change has yet to be introduced. Figure

3 demonstrates predicted effects of livelihoods on stunting with confidence intervals. While many of the intervals overlap, indicating no statistical difference between livelihood effects, the remittances and plateau livelihoods stand out as being statistically different from other livelihoods. This result demonstrates that certain livelihoods are currently more or less vulnerable to long term food insecurity, and in the future as climate changes, these may be areas to learn from or intervene in.

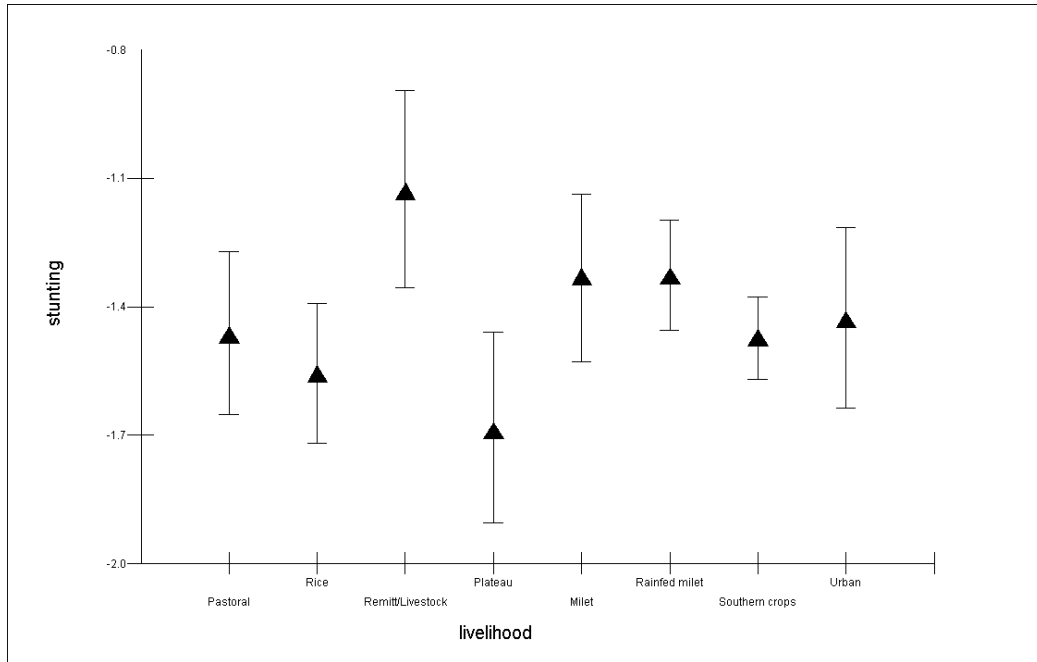


Figure 3. Livelihood effects on stunting with confidence intervals.

In order to examine the differences of clusters within livelihoods, average predicted cluster stunting was plotted by livelihood across the PPET 2000 gradient (Figure 4). This figure demonstrates that even within livelihoods, the effect of climate throughout the livelihood will have significant impacts on stunting. In a way, each livelihood develops a ‘signature’ of stunting as it moves through the PPET gradient. Interestingly, we would expect that wetter and cooler PPET would result in less stunting, and therefore see all lines in Figure 4 with a positive trend. However, there seems to be a threshold at which too much moisture starts negatively impacting stunting, and as such we see livelihoods located in the south-western part of Mali exhibiting increasing stunting as they move into the wettest areas of the PPET gradient.

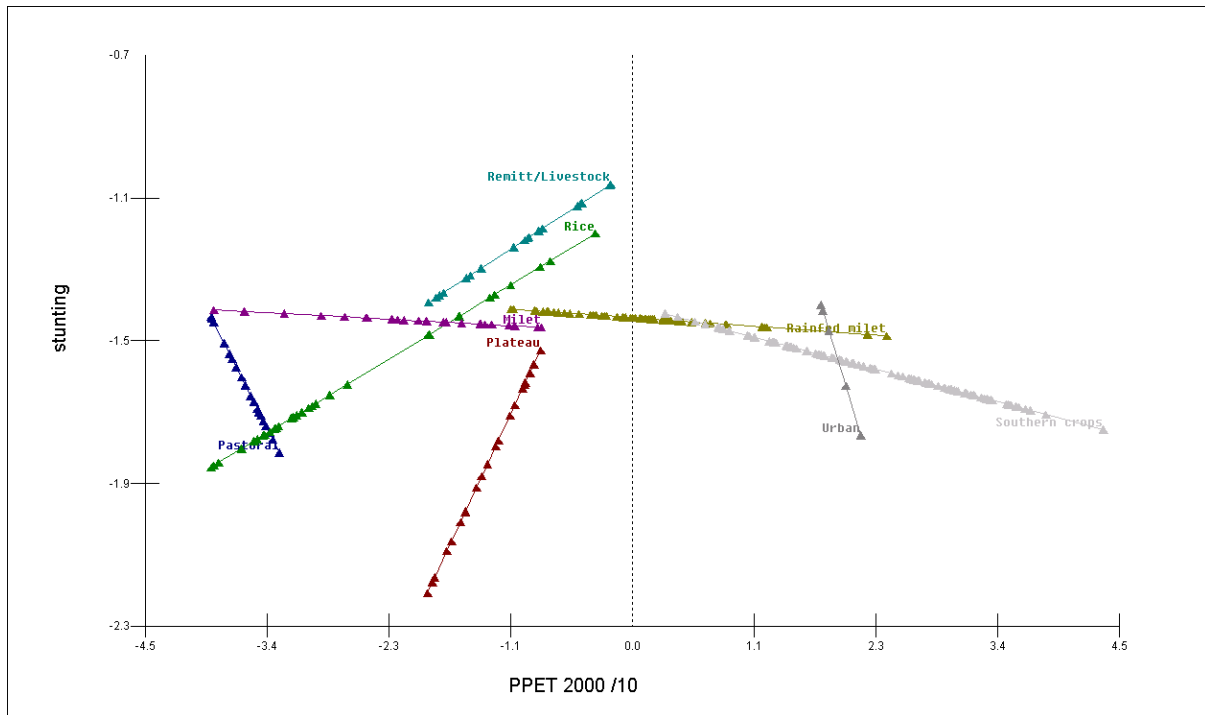


Figure 4. Predicted stunting by cluster, graphed according to livelihood and location on the PPET 2000 gradient.

Future Work

The results presented in this version of the paper are brief, but demonstrate some of the complexity inherent in modeling livelihoods and climate change effects on malnutrition. Future steps will be to incorporate the demographic change variable, and perform interaction effects of climate change and demographic change to examine how the two phenomenon may interplay to influence malnutrition. The full multilevel model will be presented, and the process will be repeated for underweight in order to assess if short term malnutrition has similar results to long term malnutrition.

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