**Using high resolution remotely sensed data to re-examine the relationship between agriculture and fertility in a pre-transitional setting**

## Introduction

Mali reports one of the highest fertility levels in the world (total fertility rate (TFR) = 6.8) and despite fairly widespread knowledge of contraceptive technologies, Mali also reports one of the lowest contraceptive use rates in the world. Most Malians grow their own food or rely on locally grown food to feed their families. However, because Mali is landlocked and is potentially facing a loss of existing arable land due to climate change, concern over the ability of the country to meet the nutritional needs of its growing population is high. Most of the contemporary discussions of Malian food insecurity and Malian fertility and contraceptive use occur with little attention to the potential link between reproduction and environmental/agricultural change. Food security scientists acknowledge the population growth challenges and reproductive health scientists acknowledge issues related to malnutrition, yet researchers rarely combine their insights and the recent advances in spatial analysis to explore the relationship between food insecurity and reproduction. Our goal in this research is to re-examine the impact of food insecurity on fertility outcomes taking advantage of the geo-referenced health data and recently developed analytic strategies from remote sensing. We hypothesize that when individuals or households experience episodes of food insecurity that the context of insecurity will be reflected in fertility outcomes and possibly in fertility intentions.

To examine this relationship we rely on the Demographic and Health Survey (DHS) survey data (representative of the entire country) as well as on a collection of remotely sensed imagery. The timing of women's births and pregnancies and information about their contraceptive use and fertility intentions are recorded in the DHS (data is retrospective). We use high resolution remotely sensed imagery (approximately 1 meter) in combination with a suite of remotely sensed data (rainfall, normalized difference vegetation index (NDVI), slope and elevation) to estimate cultivated area at the community level for the years preceding the DHS survey (see Grace et al 2012 and Marshall et al 2011). Combining estimates of cultivated area, a key input for determining food insecurity, with fertility and health data, allows us to explicitly examine the impact of changing environmental and food production contexts on demographic and health outcomes. These results are particularly relevant due to the high population growth which is characteristic of Mali (as well as its neighbors Burkina-Faso and Niger that are facing similar population growth). Additionally, because this area of the Sahel is likely facing increasing temperatures and a resulting decrease in arable land, food insecurity here is anticipated to increase in the coming years. Through an examination of fertility in a context of a warming country we can better understand the potential impacts of climate change on population and health.

## Linking Agriculture and Local Food Production with Fertility and Reproductive Health

There is abundant research examining the link between food or malnutrition and reproductive outcomes (see for example, Bailey et al 1992, Panter-Brick 1996, Gray 1983, Bentley et al. 1993, Ellison et al. 1993, Bongaarts 1980). Historically researchers have focused on three primary links relevant to pre- or early-transitional populations – marital/coital disruption, infecundity due to poor nutrition and conception failure (or miscarriage). Among agriculturalists, an increase in household labor associated with busy seasons (the harvest, for example) may result in reduced coital frequency, resulting in fewer pregnancies. Too little food may reduce fecundity by inhibiting conception or may reduce fertility through an increased likelihood of early fetal loss (miscarriage) ( see discussion in Panter-Brick 1996).

Researchers also noted that there may be psychological tolls associated with reduced food or a low harvest output (Lindstrom and Berhanu 1999, Bongaarts and Cain 1981, Caldwell and Caldwell 1992, Kidane 1989) . The stress associated with this food insecurity may have an impact on both fecundity and it may as well impact short term fertility goals, perhaps resulting in an increase in contraceptive use. A reduction in fertility will then be seen as an outcome of food insecurity.

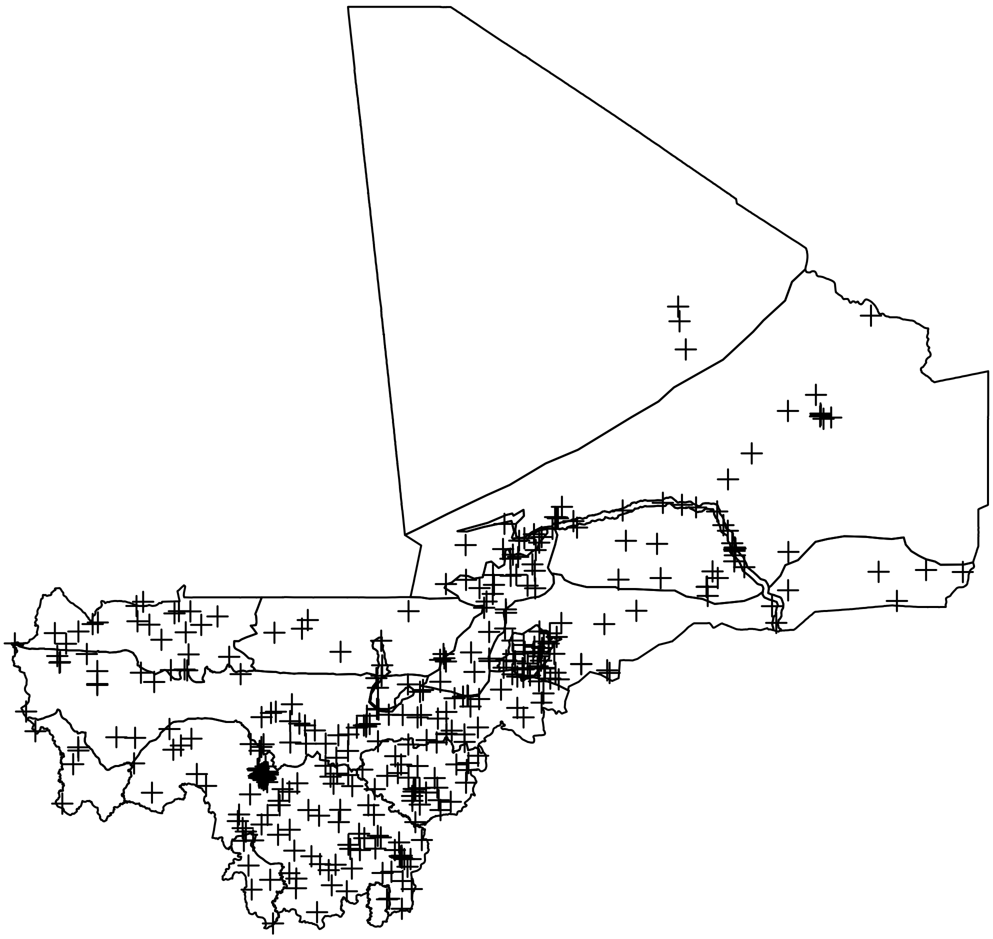
We build on this research foundation by examining smaller scale trends in fertility behaviors with smaller scale estimates of locally produced food. Instead of using country-level aggregate estimates of food production or food availability, we explicitly calculate estimates of cultivated area (a proxy for food production) for each growing season at the approximate level of a community (an area of about 10 km x 10 km). Births, miscarriages and contraceptive knowledge/use of individuals living in each of these communities can then examined within the context of variations in food production over time and space.

## Data

Two primary types of data are necessary for our analysis: demographic and health survey data and landscape/environmental data.

*Demographic/health data*: We rely on the Mali DHS data from both 2006 and 2001. These data are geo-referenced at the level of the community (approximately 20 households are within each of these DHS-defined communities). These data contain retrospective birth, pregnancy and children’s death information for each respondent (generally the data is most accurate for births and pregnancies that have occurred within the 36 months preceding the survey). The data also contain extensive information about maternal education, maternal health and information about household resources and income and the respondent’s length of time in current residence.

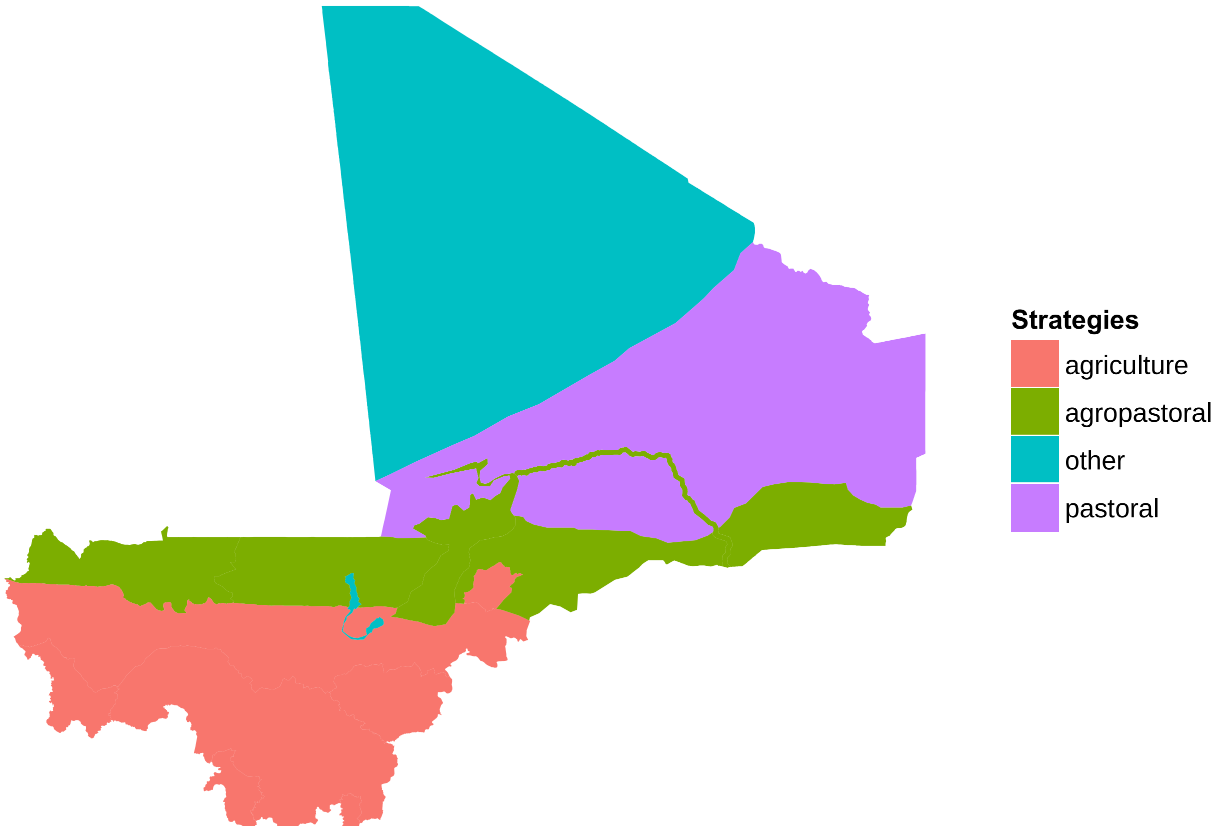
**Figure 1: Georeferenced DHS Data**



Note: Crosses represent locations of DHS community clusters (containing roughly 20 households). The large polygons dividing the country represent FEWS NET livelihood designations (not aggregated).

*Environmental and Landscape data:* To conduct our analysis we use two different but related types of environmental data: livelihood classifications as defined by the Famine Early Warning System Network (FEWS NET) and seasonal estimates of cultivated area. Livelihood data is useful for identifying the primary sources of food and income of households within a particular area. The FEWS NET livelihood zones are constructed using climate and environmental data in combination with the knowledge of local experts and the input of local residents. We use this data to classify communities as agriculturalist, pastoralist or agropastoralists and to isolate the relevant hunger and harvest seasons.

**Figure 2: Dominant Livelihood Strategies**




Note: These categories represent aggregations based on data found in the FEWS NET livelihoods profile of Mali. The "other" category contains urban areas, a small area of irrigated rice fields and, in the north, nomads/traders.

**Table 1: Relevant time periods for agriculturalists and pastoralists**

| Livelihood | Harvest | Hunger season | Rainy season |
|---|---|---|---|
| Pastoral | NA | April-July | May-Oct |
| Agriculture | Oct-Dec/Jan | July-Oct | |

Note: table is based on the FEWS NET timeline for Mali found here: http://v4.fews.net/Pages/timelineview.aspx?gb=ss&tln=en&l=en

We construct our own estimates of community-level cultivated area to serve as a measure of local food production. Communities characterized by larger amounts of cultivated area generally will have both higher labor requirements during harvest but will also produce more food therefore facing less food insecurity during the hunger season. To construct these estimates we rely on manual interpretations of very high resolution (1 meter) imagery for a geographically representative set of points. We lay a regular grid of points 500 meters apart over each high resolution image. Each point is then carefully characterized as cultivated or non-cultivated.

Generalized additive models (GAM) serve to link external landscape data – elevation, slope, rainfall – to aggregated interpretations. For locations not covered by high resolution imagery (ie; places that we were not able to "visit" via remote sensing) but with geophysical characteristics within the observed range, the classification of "cultivated" or "not-cultivated" is estimated from the GAMs.

After collecting interpretations of the very high resolution imagery and constructing grids of points spaced at 250-500 meters, we will then build a cultivated area prediction model for locations without the very high resolution data using variables with established relationships to cultivation – rainfall, slope and elevation (SRTM DEM). Because we are working with points spaced 250-500 meters apart, fine resolution data is required. We will also include both the 250 meter resolution MODIS Normalized Difference Vegetation Index (NDVI) (a measure of greenness) and a measure of soil moisture (~250 meter resolution). For each of these dynamic variables we will calculate seasonal maximum values and anomalies for use in the model. The fine scale of the explanatory data ensures that potentially important localized variations in landscape and topography are captured rather than masked through spatial averages.

Our high resolution imagery was gathered during 2011 growing seasons. This imagery will be used to form the basis of the quantitative model that will be used to construct estimates for previous and future years using the GAMs. To construct the estimates of cultivated area for non-2011 growing seasons we will rely on the same explanatory variables except will update the dynamic variables (NDVI, rainfall and soil moisture) to correspond to the relevant measures for the season of interest. In other words, we will construct a model estimating 2011 crop density based on 2011 rainfall, soil moisture and NDVI values. We will use the same model to estimate the cultivated area in the years corresponding to the DHS data – 2006, 2005, and 2004 - except we will replace the 2011 dynamic variables with the values observed in each of the years of interest. In this way we can use current information and crop models to construct a general model of cropped area which will inform estimates of past behavior.

The quality of estimates of past agricultural productivity will be evaluated in two ways: 1) we will compare estimates with results conducted agricultural surveys and 2) we will select a sample of high resolution imagery from each of the previous growing seasons and compare the 1 meter resolution images with our model-based estimates of crop density.

**Methods**
In this analysis we examine the impact of agriculture on births and miscarriages in Mali. To conduct this we will apply two different methodological strategies. First, we will describe seasonal variations in births and miscarriages for the three dominant groups (according to livelihood strategy) – pastoralists, agriculturalists and agro-pastoralists. We will construct monthly profiles of births and miscarriages for each group. These profiles will be constructed for each of the three years to compare variations in seasonal behavior over time as well as to compare the two groups.

Given that the populations within the agriculturalists and pastoralists groups are likely heterogeneous in terms of education, socio-economic status, age and other socio-demographics we will also conduct an individual-level analysis of births and miscarriages. We will construct event-history models (separate sets of models for pastoralists, agriculturalists and agropastoralists) where we will model the likelihood of an individual experiencing a birth or miscarriage during the hunger season (for miscarriages) or 9 months after the hunger season (for births). In these models we will include individual-level correlates linked to fertility – maternal age, education and parity – as well as household-level wealth information. We will also include community-level food production information – specifically the amount of cultivated area during the most recent growing season – as a means of measuring the impact of variation in food production on fertility.

The first more macro-level analysis will enable the identification of trends in births or miscarriages that correspond to seasons of interest for each of the dominant livelihood strategies found in Mali. This portion of the analysis will also help us identify larger-scale trends in fertility behavior as well. The second portion of the analysis, employs the agricultural data directly and enables us to estimate the strength of the relationship between agricultural productivity and fertility at a fine scale. The event-history models also enable us to adjust for individual- and household- level characteristics that may mitigate against food insecurity during times of lessened food availability.

**Anticipated Results**

We anticipate that our results will yield insight into the relationship between agriculture and reproductive outcomes in a pre-transitional, subsistence-based population. Beyond identifying large and small-scale trends in the seasonality of births and miscarriages, this analysis directly links one of the major components of subsistence based food systems – amount of area under cultivation – to fertility. The results can be used to estimate how changes to local food systems may impact population change in Mali. We anticipate that the results will also be helpful in similar studies examining the link between population and agriculture in Burkina-Faso and Niger – the two neighboring, landlocked West African countries.

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