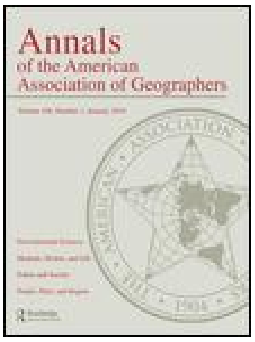

Annals of the American Association of Geographers

ISSN: 2469-4452 (Print) 2469-4460 (Online) Journal homepage: http://www.tandfonline.com/loi/raag21

# Can Small-Scale Agricultural Production Improve Children's Health? Examining Stunting Vulnerability among Very Young Children in Mali, West Africa

Kathryn Grace, Nicholas N. Nagle & Greg Husak

# Can Small-Scale Agricultural Production Improve Children's Health? Examining Stunting Vulnerability among Very Young Children in Mali, West Africa

Kathryn Grace,* Nicholas N. Nagle,† and Greg Husak‡

*Department of Geography, Environment and Society, University of Minnesota
†Department of Geography, University of Tennessee
‡Department of Geography, University of California, Santa Barbara

Stunting affects an individual's educational and wage-earning potential and can even affect the next generation of children. Most research of childhood stunting focuses on the determinants and correlates that lead to stunting—through nutritional or early infant experiences, with one potential solution to stunting being an increased supply of locally produced food. This research examines the interplay of community-level cropped area as a factor relating to childhood stunting. We use the most recently collected Demographic and Health Survey (DHS) data for Mali, very high resolution remotely sensed imagery, and other remotely sensed data relating to geophysical characteristics to examine the impact of local cultivation on children's health. We focus on evaluating the environmental, community, household, and individual characteristics of the children who report healthy anthropometrics despite the presence of specific stunting risk factors. In adopting this approach to studies of children's health we can shed light on how small-scale agricultural production impacts childhood stunting among at-risk children. *Key Words: agriculture, children's health, development, food insecurity, stunting.*

发育迟缓影响着个人的教育与收入潜能, 甚至可能影响下一世代的儿童。针对儿时发育迟缓的研究, 多数聚焦其决定因素, 并将导致发育迟缓之因——透过营养或早期幼儿经验——与增加在地生产的粮食供给这项解决发育迟缓的可能方案相互连结。本研究检视社区层级耕作区域的互动, 作为与儿童发育迟缓相关的因素。我们运用马利最近期搜集的人口与健康调查（DHS）数据, 相当高解析度的遥测影像, 以及与空间物理特徵有关的其它遥测数据, 检视在地耕作对儿童健康的影响。我们聚焦评估儘管存在着特定发展迟缓风险因素, 但仍被通报为人体测量健康的儿童的环境、社区、家户与个人特徵。我们透过採用此般研究儿童健康的方法, 得以对微观尺度农业生产如何影响身处风险的孩童的儿时发育迟缓提出洞见。 *关键词： 农业, 儿童健康, 发展, 粮食不安全, 发育迟缓。*

El retraso en el crecimiento afecta el potencial educativo y salarial de un individuo y puede incluso afectar a la siguiente generación de niños. La mayor parte de la investigación sobre retraso en el crecimiento infantil se concentra en los determinantes y factores relacionados que conducen a retrasar el desarrollo físico—a través de condiciones nutricionales o experiencias de la infancia temprana, con una potencial solución a este problema representada en un mayor suministro de alimentos producidos localmente. Esta investigación examina a nivel de comunidad la interacción en el área sembrada como un factor relacionado con el retraso en el crecimiento infantil. Usamos datos del Estudio Demográfico y de Salubridad (DHS) sobre Malí, completado hace poco tiempo, imágenes de percepción remota de muy alta resolución y otros datos de sensores remotos, relacionados con características geográficas físicas, para examinar el impacto de la agricultura local sobre la salud de los niños. Nos concentramos en la evaluación de las características ambientales, comunitarias, familiares e individuales de los niños, que registran una antropometría saludable a pesar de la presencia de factores riesgosos específicos de retraso en el crecimiento. Adoptando este enfoque para el estudio de la salud infantil, podemos hacer luz sobre el modo como la producción agrícola a pequeña escala impacta con retraso en el crecimiento infantil entre los niños en riesgo. *Palabras clave: agricultura, salud de los niños, desarrollo, inseguridad alimentaria, retraso en el crecimiento.*

Stunting occurs when children are significantly shorter than average for their age. Although short stature alone is not necessarily a health or development issue, stunting is a powerful indicator of other physical, emotional, cognitive, and related developmental challenges that do represent significant health and development issues (Rodier 2004; Grantham-McGregor et al. 2007). Stunting is linked to

*Annals of the American Association of Geographers*, 106(3) 2016, pp. 722–737 © 2016 by American Association of Geographers
Initial submission, March 2015; revised submission, July 2015; final acceptance, September 2015
Published by Taylor & Francis, LLC.

increased risk of illness or death, reduced educational attainment, reduced earnings, and an increased likelihood (for girls) that the next generation will be stunted as well (Strauss and Thomas 1998; Alderman, Hoddinott, and Kinsey 2006). Stunting among children under five years of age is a result of inadequate food and calories, experiences with frequent illness, poor care[1]—including improper breastfeeding and other feeding practices—and low weight at birth and is generally unrelated to ethnicity or race (Habicht et al. 1974; Bhandari et al. 2002; Grantham-McGregor et al. 2007; Black et al. 2008). Based on these factors, stunting determinants can be organized into three primary categories: biological, behavioral, and environmental.

Because almost 40 percent of children under age five in the developing world suffer from stunting, understanding the community, household, and individual components that lead to stunting is vital as many countries aim to improve children's health and development. Although policies and research focused on reducing stunting attempt to address these issues in different ways, they almost always center on risk reduction strategies (Balk et al. 2005; de Sherbinin 2011). These strategies tend to revolve around general poverty reduction, improving food availability and access, improving health care availability, teaching parents about nutrition, and improving prenatal care to reduce the incidence of low birth weight (see the UNICEF framework of Smith and Haddad 2000).

This research focuses on Mali, one of the poorest countries in the world, where food insecurity, malnutrition, and childhood health issues are common. We use a combination of population health, environmental, and remotely sensed data to evaluate the role of one commonly identified cause of stunting—inadequate food production (UNICEF 1990; Young 1994; Frongillo, de Onis, and Hanson 1997). Instead of looking at food production deficits, however, we examine the expected positive impact associated with higher than average food production.[2] Specifically, we evaluate the potential for increased community-level cultivated area to reduce the negative impact on children's health outcomes associated with commonly cited behavioral or biological stunting risk factors (stunting preconditions). This approach provides an alternative and unique perspective to understand the ways in which households in poor countries are able to raise healthy children despite notable limitations.

## Background

Childhood stunting, a measure of malnutrition and chronic food insecurity, is characteristic of many children in the developing world, and stunted children are more likely to face severely negative health and economic impacts in both the short and long term. Because many of the countries faced with high rates of stunting are also emerging economies, the long-term negative social and economic outcomes of individual-level stunting could affect the long-term, macrolevel economic development of these countries. Stunting often stems from chronic food insecurity; therefore, foregrounding the different components of the four pillars of food security[3]—access, availability, stability, and utilization—lies at the heart of developing solutions to reduce stunting (Smith and Haddad 2000).

After Sen's highly influential work identifying access to food as a key, yet poorly understood, component of food insecurity in the 1980s and 1990s, research interest shifted to access to food (or land) as being one of the most important component of food insecurity (Sen 1981; Erickson 2008). Some argued that at regional scales, food production, an indication of food availability, was adequate to meet the needs of a large and growing population (Dyson 1996; Sen 1999; Devereux and Edwards 2004). None of the models that provided the basis for these conclusions, however, considered subnational disparities or variability (Devereux and Edwards 2004). Now, there is significant and growing concern regarding the impact of climate on food availability, specifically how changes in the amount of food produced can occur as a result of climate change and variation and how these issues fluctuate at subnational scales (Funk and Brown 2009; Godfrey et al. 2010; Lobell et al. 2011). One of the solutions to food insecurity based on the "availability" pillar and proposed by development agencies is to increase small-scale food production in subsistence communities as a way to combat the negative health outcomes associated with food insecurity (see work by the Food and Agriculture Organization, Food for Peace, and others, as well as Godfrey et al. 2010).

Whereas some researchers continue to examine issues relating to utilization, food access, or stability, this project specifically examines and quantifies the link between cultivated area and malnutrition at the individual level. We evaluate the relationship of community-level variation in cultivated area, a proxy measure of food production, on children's health outcomes. This analysis therefore explores one of the vital linkages of stunting and food insecurity to quantify the ways in which individuals and community food production interact. We evaluate the role that increased agricultural production plays as a protective characteristic (Engle, Castle, and Menon 1996) of children who have some of the most commonly cited risk factors or preconditions for stunting but who are not actually stunted. We consider healthy children with risk factors for stunting to be *resilient*.[4] This analytic framework[5] centers attention on the children who are able to develop in a healthy way even though they are characterized by other important risk factors (Zeitlen 1991).

In Mali, where the majority of the population relies on subsistence agriculture and pastoralism for food, the share of children under age five who are stunted hovers around 30 percent (CPS/SSDSPF 2012/2013). At the aggregate level there is some indication that stunting is based on environmental characteristics, possibly related to food production, because the more arid areas in the north and east have higher levels of stunting, whereas communities in the more lush growing areas in the south and west typically report less stunting (CPS/SSDSPF 2012/2013). Among the strategies in place to combat stunting and other issues related to food insecurity, nongovernmental organizations continue to invest resources into improving the small-scale farming of many Malians (see, e.g., the World Food Program's Mali agriculture interventions). In terms of general stunting preconditions or risk factors, Mali is also characterized by higher than average rates of low birth weight, poverty, and low parental educational attainment (CPS/SSDSPF 2012/2013)—factors positively related to stunting.

Here we examine the relationship between several commonly cited stunting preconditions, or risk factors, and the impact of agricultural production on stunting outcomes of children under five years of age. The specific preconditions examined and their link to the stunting outcome are explored next and summarized in Table 1. These preconditions were selected because they are cited in virtually all research on stunting as some of the key factors explaining why some children are stunted and others are healthy (see Black et al. [2008] as well as the UNICEF framework). Despite the high levels of investment in small-scale agriculturalists, this study represents the only country-level examination of the impact of small-scale production on childhood stunting and resilience in land-locked West Africa.

## Preconditions

### Low Birth Weight

Low birth weight—when an infant is born weighing less than 2,500 g—is the result of environmental, socioeconomic, or biological factors and is one of the underlying causes of mortality among very young

**Table 1.** Preconditions used in this analysis associated with childhood stunting

| Precondition | Relationship to stunting | References (selected) |
|---|---|---|
| Low birth weight | Children who are born LBW are more likely to be stunted. The reasons for the link between stunting and LBW relate to biology and might relate to the mother's and household's access to food. | Black et al. (2008), Grace et al. (2014), Knops et al. (2005), Gutbrod et al. (2000), Prince and Groh-Wargo (2013) |
| Low parental education | Low parental education relates to household wealth and understanding of children's nutritional needs. It could also relate to the mother's or father's care-taking ability as well as bargaining power and comfort in navigating social institutions. | Semba et al. (2008), Barrera (1990), Glewwe (1999), Handa (1999), Walker et al. (2011), Engle, Menon, and Haddad (1999), Thomas, Strauss, and Henriques (1991), Frost, Forste, and Haas (2005) |
| Mother's anthropometry: Short stature | When the mother shows indication of a history of food insecurity through this measure, this could indicate reduced household food access as well as a biological predisposition toward nutritional deficiencies that might be seen in the child. | Özaltin, Hill, and Subramanian (2010), Martorell (1989), Fishman et al. (2004), WHO (1995), Engle, Menon, and Haddad (1999), Steckel (2008) |
| Poor household | Household wealth could indicate the household's ability to access food (particularly in terms of food purchases) or needed medical care. This measure is proxied using household assets. | Haddad et al. (2003), Boyle et al. (2006), Bronte-Tinkew and DeJong (2004), Fotso et al. (2012), Black et al. (2008) |

*Note*: LBW = low birth weight.

children (Mwabu 2009; Abu-Saad and Fraser 2010; also see Kramer 1987). Additionally, children who are born with low birth weight might never "catch up" to their healthy birth weight peers physically or developmentally (Knops et al. 2005) and are more likely to be stunted as well as to show other signs of physical or developmental delays (Black et al. 2008; Victora et al. 2008). Given that low birth weight might result from reduced maternal nutrition while the child is in utero (see Grace, Brown, and McNally 2014), increasing calories or nutrition during the early years of a child's life could serve to counteract low birth weight and aid in the long-term healthy development of an individual.

### Parental Education

Maternal education has a complex yet crucial role in child health and development. A number of pathways connect maternal education to child stunting, with the general conclusion being that higher levels of maternal education produce healthier children (Engle, Menon, and Haddad 1999). Among the reasons underlying this relationship is the theory that education increases maternal knowledge of children's nutritional needs and sources of illness (Barrera 1990; Engle, Menon, and Haddad 1999). Additionally, higher levels of maternal education might increase household income or within-household maternal bargaining (Frost, Forste, and Haas 2005). Often, when the mother has control of some of the household income and is involved in household decision making, children benefit in terms of health and development (Doan and Bisharat 1990; Haddad and Hoddinott 1994). Another benefit to a higher level of maternal educational attainment is the mother's ability to navigate various social and community institutions (including health care centers or food aid organizations) because of her own experience in an institutionalized educational setting (Joshi 1994). This ability to navigate institutions could be particularly important in times or places of food insecurity.

The impact of a father's education on stunting has also been evaluated, with a higher level of education associated with healthier children (Semba et al. 2008). The mechanisms that underlie stunting and paternal education are potentially different than those for mothers and are rarely studied. In addition to more educated fathers being more likely to have more educated wives, paternal education might be associated with household income—both of which are associated with lower rates of stunting among children. Similar to the positive way in which increasing a mother's education might result in her improved understanding of a child's nutritional needs, a more educated father could also bring a greater understanding of a child's nutritional needs (Semba et al. 2008). In general, children with less educated parents are more likely to be stunted than those with more educated parents in food insecure environments. Here, we evaluate whether increased food production can help to overcome the parental education barrier to healthy child development.

### Mother's Anthropometry

Mother's height (which might be based on her own experiences as a stunted child or based on her genetics) is also strongly correlated to child stunting. Shorter mothers are more likely to have stunted children (Özaltin, Hill, and Subramanian 2010). Although the stunting metric in children under five years of age is used as a measure of malnutrition because it is not subject to genetic variations (essentially all children under five should be around the same height regardless of genetic predisposition), a mother's own experience as a stunted child could be expressed in her own child's stature (World Health Organization [WHO] 1995; Engle, Menon, and Haddad 1999).

The height of the mother might reflect the behavioral components of poor nutrition. In other words, the mother might feed her children and respond to their nutritional needs in the same way that her needs were addressed during her childhood, resulting in the same stunting outcomes (Steckel 2008). Additionally, a stunted mother's physical development might also be so impaired that she was unable to produce a healthy height child (Martorell 1989; Özaltin, Hill, and Subramanian 2010).

### Household Poverty

Poverty and stunting are strongly related—stunted children are more likely to come from poor households (Black et al. 2008). Because stunting is a measure of chronic food insecurity, one pathway linking stunting and poverty is through a household's access to food (Haddad et al. 2003; Fotso et al. 2012). If a household is unable to purchase food because of inadequate economic resources, the members of the household might show signs of food insecurity and malnutrition (Smith and Haddad 2000). Poverty could also reduce the amount of land a household can access, as well as the farming inputs (fertilizer, seed, paid labor, and other related technologies) that would increase the amount of food available to a household. This could be particularly significant in subsistence-based communities where a household's ability to produce and store their own food is vital to food availability and stability.

As with the previously mentioned preconditions, of the underlying mechanisms linking poverty to childhood stunting, one solution to reduce stunting is an increase in locally available food (which could increase local food supply and decrease prices or could indicate improved subsistence agricultural conditions). We explore the impact of increased local agricultural production, as measured by cropped area, on these preconditions to determine the relationship among preconditions, agricultural production, and stunting. Local-level cultivated area provides a proxy measure of local food availability, one of the four pillars of food security. Because there are other factors that could complicate a straightforward relationship, however, we also include a set of control variables to adjust for additional variation that might come from household or individual characteristics. The data used and variable constructions are further explained in the following section.

## Data

To examine a child's resilience to stunting as mediated through agricultural production, we include variables to measure the preconditions, agricultural production, as well as factors known to correlate to variations in child height. We rely on two primary types of data: environmental (including remotely sensed) and population and health survey data.

### Population and Health Data

The Demographic and Health Survey (DHS) provides detailed information on households and individuals throughout the country and is the best source of high-quality health data available for most countries of the Global South. We use the most recent data from 2012–2013 with an overall sample size of approximately 10,000. We select the youngest child from each family who is at least one year old but no more than five years old. By selecting one child per family we remove the within-family correlation issue that could complicate a straightforward statistical analysis. Further, by selecting the youngest child, we can be more assured of any information recalled by the mother (e.g., relevant for birth weight) and the appropriateness of using information gathered at the time of the survey (e.g., flooring or household wealth).

The data are geographically referenced at the community level—approximately twenty households are within each community—enabling us to merge the DHS data with the environmental data. To protect confidentiality, the spatial coordinates are shifted by 0 to 5 km in any direction (a small number, 1 percent, are randomly shifted 10 km). We assume that the community falls within some 10-km radius of the provided spatial coordinates. From these data we gather the child- and household-specific information on preconditions as well as series of standard control variables used in stunting analyses. The list of included variables and their descriptive characteristics can be found in Table 2.

### Environmental (Food or Agricultural Production)

We use high-resolution remotely sensed imagery (~1 m) combined with coarser resolution (~250–1,000 m) landscape data (rainfall, slope, Normalized Difference Vegetation Index [NDVI]) to indirectly estimate our agricultural production proxy measure—community-level cultivated area. We estimate cultivated area for each year of the child's life, including the pregnancy period, within each community. We link the cultivated area estimates to a child's experience by using the child's birth date and the location of the DHS sampling cluster. The sampling cluster is a geographic location that represents the centroid of the residential area where the child lives.

Ideally, we would have a direct measure of community-level food production, but such data do not exist. We indirectly measure production by the area under cultivation around each DHS village for each year of the child's life. We then take the average of cultivated area over the life of the child to provide a single estimate of cultivated area over the child's life. Although cultivated area is not a direct measure of food production, it is strongly related to food production and food availability and is routinely monitored as a critical input of early warning systems (e.g., Famine Early Warning Systems) to help identify food insecurity potential (Husak et al. 2008; Grace et al.

**Table 2.** Descriptive characteristics of independent and dependent variables used in the analysis

| | Variables | The units or the level of the variables | M | Median | *SD* | Minimum | Maxium | Count |
|---|---|---|---|---|---|---|---|---|
| Independent variables | Birth year | Child's birth year | | | | | | 2008 = 517<br>2009 = 867<br>2010 = 1,387<br>2011 = 1,839<br>2012 = 2,097<br>2013 = 29 |
| | Sex | Child's sex | | | | | | Male = 3,466<br>Female = 3,270 |
| | Birth order | Child's birth order | 3.89 | 4 | 2.36 | 1 | 14 | |
| | Mother's age | Categorical age of mother in 5-year age groups | | | | | | 15–19 = 618<br>20–24 = 1,436<br>25–29 = 1,759<br>30–34 = 1,369<br>35–39 = 949<br>40–44 = 453<br>45–49 = 152 |
| | Rural | Categorical variable for type of place of residence, 0 for urban and 1 for rural | | | | | | Urban = 1,779<br>Rural = 4,957 |
| | Cultivated area (community-level) | Average percentage cultivated area in a community (10-km-diameter circle) over child's lifetime | 0.04 | 0.02 | 0.07 | 0.00 | 0.55 | |
| | Livelihood zone | Categorical variable for dominant livelihood zone of the community | | | | | | Irrigation = 142<br>Bamako = 1,049<br>Agricultural = 4,551<br>Agro-pastoral = 983 |
| Preconditions | | | | | | | | |
| | Low birth weight | Categorical variable for child's birth weight status. Less than 2,500 g at birth is considered low birth weight | | | | | | Yes = 506<br>No = 1,849 |
| | Household wealth index | Categorical index variable created by DHS using principal components analysis related to household assets | | | | | | Poorest = 1,287<br>Poorer = 1,334<br>Middle = 1,298<br>Richer = 1,292<br>Richest = 1,525 |
| | Floor | Categorical variable for type of flooring in the residence: 0 for unfinished flooring (dirt, sand, dung, earth) and 1 for finished flooring (wood, carpet, cement, tile) | | | | | | Unfinished = 4,774<br>Finished = 1,932 |
| | Mother's height | Continuous height for age standard deviations from the WHO reference median | −0.26 | −0.25 | | −5.65 | 5.45 | 3,464 |

(*Continued on next page*)

**Table 2.** Descriptive characteristics of independent and dependent variables used in the analysis *(Continued)*

| | Variables | The units or the level of the variables | M | Median | *SD* | Minimum | Maxium | Count |
|---|---|---|---|---|---|---|---|---|
| | Mother's education Partner's education | Categorical variable for level of completed education | | | | | | Mother<br>None = 5,416<br>Primary = 640<br>Secondary = 625<br>Higher = 55<br>Father<br>None = 5,289<br>Primary = 509<br>Secondary = 633<br>Higher = 155 |
| Dependent variable | | | | | | | | |
| | Stunting | Categorical variable using the DHS calculated height for age *z* scores. If *z* score is −2 or lower then the child is considered stunted; otherwise, the child is considered not stunted | | | | | | Not stunted = 1,812<br>Stunted = 1,018 |

*Note*: DHS = Demographic and Health Survey; WHO = World Health Organization. Data are rounded up.

2012; Grace , Husak, and Bogle 2014; Grace and Nagle 2015).

Because most of the communities in Mali are dependent on small-scale subsistence and rain-fed agricultural systems, communities characterized by larger amounts of cultivated area generally will produce more food or, if they grow large amounts of cash crops, more money. In both cases we assume that the greater the cultivated area the more food or money is present in each village, thereby suggesting greater food security throughout the year. In Mali, land is typically divided according to the community chief—traditionally he alone has land rights (Benjaminsen and Sjaastad 2002). Although land is not necessarily equally divided within a community, it is cultural practice for community members to share food with children, although not necessarily with adults.[6] Given these cultural practices, community-level cultivation can be justified as a measure of food in the community.

Further, although cultivated area is a valuable indicator of food security at the household, neighborhood, or community level, few data document cropped area at this scale for most agriculturally dependent areas in Africa, including Mali. National governments produce data related to cultivated area, but those data are collected at an aggregate spatial scale (political districts) and are therefore generally inapplicable to household-level analyses. No other annual crop data exist, including annual maps of cropped area. Hence, we construct our own estimates of community-level cultivated area to measure local food production and help explain the variation in children's stunting outcomes.

Because we only know the approximate—within 5 km—location of the DHS community, the resolution of the remotely sensed imagery (~1 m) is higher than can be reliably matched to the survey data. Through statistical processing, however, we can use these high-resolution data to provide estimates of the local cultivated area (see Husak et al. [2008]; Grace et al. [2012]; Grace, Husak, and Bogle [2014]; Grace and Nagle [2015] for similar applications). To estimate community-level cultivated area for each child, we estimate cultivated area from a predictive model of moderate- and low-resolution data and trained using manual interpretation of very high-resolution (1 m) imagery for a geographically representative set of locations. The predictive model uses environmental variables with established relationships to cultivation: the NDVI,[7] rainfall, and population density. These variables are available for the entire country of Mali.

The cultivated area prediction model is developed using data from manual interpretation of imagery, conducted by a trained team of analysts familiar with Malian physical geography. The team uses the Rapid

Land Cover Mapper Tool to process the high-resolution imagery as described in Husak et al. (2008). The high-resolution data set included IKONOS and Quickbird panchromatic images from late September through late November of 2011, 2012, and 2013 (i.e., the height of the cultivation season) at 1.0-m and 0.6-m resolution, respectively. For each image, we lay a regular grid of points over it, 250 or 500 m apart. Each point is then classified as cultivated or noncultivated. Because we only have the high-resolution imagery for a portion of the country, we use the classified points in a binomial regression model to predict the landscape characteristics in places where we do not have high-resolution imagery.

The predictive model is the following binomial model:

$$\text{Logit}(crop_{st}) = f(x, y) + f(\text{maximum NDVI}_{st}) + f(\text{total rainfall}_{st}) + f(\text{popden}_{s}),$$

where the dependent variable is the data obtained from the interpretation of the high-resolution imagery, NDVI is the maximum NDVI for a season from the MODIS MOD13Q1 product, total rainfall is the seasonal total from the Africa Rainfall Estimate Climatology Version 2, and population density is a 3-km moving average of population density from the AfriPop project (afripop.org). The smoothing functions, f, are automatically determined using smoothing spline models fit by Generalized Additive Modeling in the mgcv package of R (Wood 2011). The fitted spline over the spatial coordinates is a large spatial trend that is not captured by the trends in NDVI and rainfall across the study region. We are, however, not interested in the ability to infer individual covariate effects but rather in the model's ability to predict cultivated area. The explained deviance over the training data was 17.5 percent ($p < 1e\text{-}8$). The model is described in more detail in Grace and Nagle (2015).

We consider two sources of error caused by using cultivated area estimate in regression models: the positional error from the random perturbation of the village Global Positioning System coordinates and the statistical error from using a prediction rather than the truth. Following the recommendation from DHS, we obtain estimates by averaging over a larger region (10 km) than the usual positional error (0–5 km). Intuitively, the 10-km disk centered at the true location is similar to a 10-km disk that has been displaced by zero to 5 km. DHS displaces points using a "random direction, random distance" approach (Burgert et al. 2013, 9); hence, the expected overlap between two 10-km disks is 84 percent. We claim that the error due to dislocation is of less concern than the error arising from prediction and spatial smoothing across the 10-km region.

When spatially smooth estimates are used as proxies for true environmental effects, the effect of this measurement error on regression coefficients is one of Berkson measurement error rather than classical measurement error (Lopiano, Young, and Gotway 2010). Unlike classical measurement error, which can induce coefficient bias in linear regression models, Berkson measurement error does not. In nonlinear models, however, such as the binomial regression model we use to describe health outcomes, Berkson error can introduce some bias (Carroll et al. 2006). In general, the bias tends to reduce estimated effects, so we caution that our results are more likely to underestimate true effects than to overestimate them.

In addition to the cultivated area estimates, we also use USAID's Famine Early Warning System's (FEWS NET) livelihood zone data. These data provide general descriptions of the dominant strategies communities use to earn money and produce food. These categories are constructed based on qualitative and quantitative information related to local knowledge of culture and land use as well as rainfall, elevation, and economic trends. For this study, we assume that communities that fall within the same livelihood zone are going to share characteristics that we have not accounted for explicitly in this analysis but that could be related to overall food production. We incorporate livelihood zones as fixed effects in our statistical analysis. Figure 1 presents the livelihood zones and the DHS clusters across Mali.

## Methods

Much of the literature on children's stunting highlights risk factors and vulnerable groups (e.g., Black et al. 2008; de Sherbinin 2011; Fotso et al. 2012). The straightforward identification of characteristics of families or communities that fail to produce healthy children could inhibit successful intervention projects because the focus is not on how success occurs but on how failures occur (see Pryer, Rogers, and Rahman 2004). In other words, in the event that research isolates a factor associated with a negative health outcome of a child, the inverse of this factor is not necessarily associated with the positive health outcome of the child. The way to identify characteristics of healthy children and the direction of impact is to

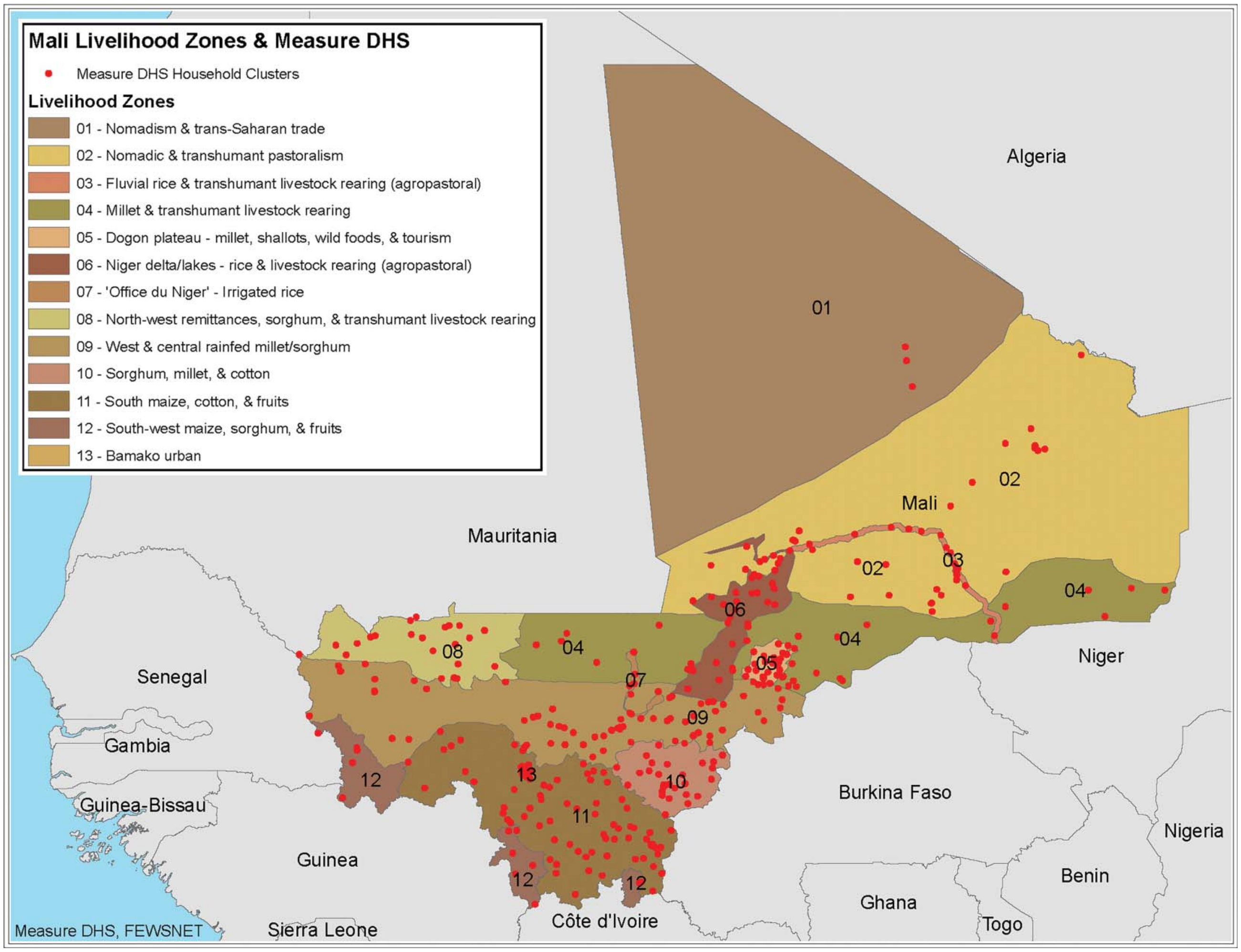


**Figure 1.** Mali livelihood zones and Demographic Health Survey data clusters. *Note:* DHS = Demographic Health Survey. (Color figure available online.)

switch attention to healthy outcomes. Adopting this approach, we explore the impact of agricultural production on children who, because of some set of biological, behavioral, or environmental factors, are considered vulnerable to stunting yet are not currently stunted. We then profile the environmental and physical factors of these resilient children.

We construct both standard generalized linear models (GLMs) and generalized linear mixed models (GLMMs; also known as multilevel or random effects models) through the linking of food production data to other relevant individual- and community-level features gathered from DHS. Consistent with the research goal of examining child stunting, the dependent variable is the categorical stunting variable as determined by each individual child's height for age measure. As mentioned in the previous section, we include a variety of independent variables and model specifications. At the household level, we include maternal anthropometry (height), parental socioeconomic characteristics, household size, and household assets. Finally, at the finest level, we evaluate the specific characteristics of the child, including age, sex, birth order, and anthropometric information. These variables are presented in detail in the preceding sections and are presented in Table 2.

Next we identify specific indications of community-, household-, or individual-level susceptibility and evaluate children's health outcomes within these vulnerable groups. Specifically we evaluate and compare stunted versus nonstunted children who are characterized by each specific precondition (as highlighted in Table 1). The precondition construction allows us to explore specific factors that the literature identified as problematic for the long-term health and development of children and families. From this point of departure we can then evaluate the role of agricultural production in producing healthy children by comparing groups of children who are identified as vulnerable yet who are not currently showing signs of ill health or development.

## Results

First, we summarize the results based on the baseline covariates (Table 3). Girls and urban dwellers are more likely to be nonstunted. Year of birth also is significant, because children born closer to the survey date are more likely to be healthy. This relationship is likely capturing the age of the child, because the stunting metric is somewhat sensitive to age-specific growth rates. Adding other precondition variables, urban residence no longer explains variation in stunting behaviors. Instead, we see significant and positive relationships among poverty, mother's height, and the father's[8] educational attainment. We see no significant impact of community-level food production in this model.

**Table 3.** Binomial regression baseline and full model

| | Baseline model | | Full model | |
|---|---|---|---|---|
| | Coefs. | Sig. | Coefs. | Sig. |
| Independent variables | | | | |
| Sex (female) | −0.1326 | † | −0.1694 | * |
| Birth order | 0.0064 | | 0.0061 | |
| Rural | 0.6466 | *** | 0.1985 | |
| Livelihood zone (irrigation) | | | | |
| Bamako | 0.0268 | | −0.2262 | |
| Agricultural | 0.0956 | | −0.0257 | |
| Agropastoral | 0.1063 | | −0.0644 | |
| Mean CAE | −0.0824 | | −0.2224 | |
| Preconditions | | | | |
| LBW (no) | | | −0.0035 | |
| Wealth (poorest) | | | | |
| Poorer | | | −0.2341 | * |
| Middle | | | −0.0222 | |
| Richer | | | −0.3445 | * |
| Richest | | | −0.4397 | * |
| Floor (finished yes) | | | −0.1222 | |
| Height | | | −0.0017 | *** |
| Mother's education (none) | | | | |
| Primary | | | −0.1042 | |
| Secondary | | | −0.0278 | |
| Higher | | | 0.3701 | |
| Partner's education (none) | | | | |
| Primary | | | −0.2159 | |
| Secondary | | | −0.4572 | ** |
| Higher | | | −0.2453 | |

*Note*: Stunted = 1, nonstunted = 0. Models also include child's birth year (2008–2013) and categorical age of mother. The coefficients are not included here in the interest of space. Mean CAE = mean cropped area estimate at the community level, LBW = low birth weight. Generalized linear mixed models (GLMMs; where children are nested within communities) are also constructed but not presented here. No differences in variable significance exist between the generalized linear model (GLM) and GLMM.
†$p < 0.1$.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

When we explore the precondition variables separately, different patterns emerge. Also, because we are aiming to evaluate and make conclusions about pathways to health given certain preconditions, how we analyze the data varies somewhat according to the variables under study. Although we rely on GLM regression to explore the relationships between the independent and dependent variables, the modeling strategies and the presentation of results are affected by sample size of the relevant population and whether the variable is categorical or continuous. Therefore, each precondition produces a somewhat unique presentation of results.

In terms of the anthropometric variables, we explored a child's low birth weight status and maternal height. Consistent with our accent on the strategies used to ensure healthy children, we intended to concentrate on children who were born with low birth weight but who ultimately attained a healthy height; in other words, those children who showed increased risk of stunting but who were successful in attaining a healthy height. The very small sample size—only sixty-one children born with low birth weight attained healthy heights by the survey date—however, instead required that we evaluate the larger sample of children who were born healthy and eventually become classified as stunted. Among these children, and exclusive of the baseline covariates (see Table 4), mean food production over the child's lifetime is positive and significant ($p = 0.05$). A unit increase in the percent cultivated area of a community corresponds to a reduction of 1.13 in the log odds or a reduction of about 32 percent in the odds of being stunted. If there is less food produced in their community, children are more likely to be stunted and those healthy children who live in communities with more food produced are more likely to stay healthy (nonstunted).

In terms of the wealth precondition, building on research that suggests that poverty is a key component

**Table 4.** Binomial regression results based on preconditions and food production

| Models based on preconditions | | Without baseline covariates | | With baseline covariates | |
|---|---|---|---|---|---|
| | | Coefs. | Sig. | Coefs. | Sig. |
| Model 1: Healthy weight children | | | | | |
| | Mean CAE | −1.1254 | † | −0.4544 | |
| Model 2: Wealth | Wealth (poorest) | | | | |
| | Poorer | −0.0347 | | −0.0703 | |
| | Middle | 0.028 | | −0.0384 | |
| | Richer | −0.3402 | † | −0.3161 | |
| | Richest | −0.5203 | ** | −0.4856 | * |
| | Mean CAE | 0.7713 | | 0.5513 | |
| | Interaction | | | | |
| | Poorer × Mean CAE | −1.213 | | −1.0713 | |
| | Middle × Mean CAE | −0.4318 | | −0.2029 | |
| | Richer × Mean CAE | −0.9603 | | −0.8471 | |
| | Richest × Mean CAE | −2.4032 | ** | −2.2179 | * |
| Model 3: Unfinished flooring | Mean CAE | 0.4183 | | 0.3499 | |
| Model 3a: Finished flooring | Mean CAE | −1.8897 | ** | −1.88 | ** |
| Model 4: Maternal height | Maternal height | −0.0019 | *** | −0.0018 | *** |
| | Mean CAE | −0.1747 | | −0.0871 | |
| Model 5 | Mother's education (none) | | | | |
| | Primary | −0.3667 | ** | −0.255 | † |
| | Secondary | −0.6119 | *** | −0.3792 | * |
| | Higher | −0.343 | | −0.0646 | |
| | Mean CAE | −0.13482 | | −0.0797 | |
| Model 6 | Partner's education (none) | | | | |
| | Primary | −0.3933 | ** | −0.2546 | † |
| | Secondary | −0.8397 | *** | −0.6315 | *** |
| | Higher | −0.8342 | *** | −0.5126 | † |
| | Mean CAE | −0.1529 | | −0.148 | |

*Note*: Stunting = 1, nonstunting = 0. Mean CAE = mean cropped area estimate at the community level. Generalized linear mixed models (GLMMs, where children are nested within communities) are also constructed but not presented here. No differences in variable significance exist between the generalized linear model (GLM) and GLMM.
†$p < 0.1$.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

of food insecurity, we explored the role of household wealth, as measured by the DHS wealth index and the role of household floor type. The wealth index,[9] provided by DHS, includes several different household assets to create categories of household-level wealth that can be compared across the country. Because the index is complex and contains a number of different measures of household assets that might be challenging to interpret, however, we also explored the simpler flooring variable. This variable simply groups households by the types of floor they have. One of the first things that a household with surplus resources invests in is flooring because of both the ease of care and the cleanliness that come with finished floors. This portion of the analysis evaluates the relationship between stunting and wealth (flooring) and the interaction of floor type with food production. Bivariate chi-square tests of independence ($p$ value $< 0.05$) support prior research: Children from relatively wealthy[10] households or with finished flooring are more likely to be nonstunted than poorer children or those from households with unfinished floors.

The results suggest that food production does reduce stunting; in other words, more food results in more children who are not stunted. This relationship is only true, however, for the children who are the least poor. Children in the households with the most wealth have a log odds of being stunted that is 2.40 units less than those children in the poorest households. Further, by including an interaction effect between wealth and food production, we explored the impact that more cultivated area has on these different wealth classes (see Table 4). The motivation behind this approach was to determine whether more cultivated area has a different relationship to stunting according to the household's wealth classification. Children who are the least likely to be poor are less likely to be stunted. In communities where more food is produced, they are even less likely to be stunted than similarly wealthy children from communities with less food. There is no impact of food production on the poorest children, however.

Evaluating only maternal physical characteristics and food production, we assess the relationship among food production, stunting, and maternal height. Taller mothers are more likely to have nonstunted children. The results of our models suggest that increasing food production does not reduce the stunting risk to children associated with short-statured mothers. Further, even in selecting out the nonstunted children of the shortest mothers (not shown in Table 4), agricultural production could not explain their healthy nonstunted height outcome compared to the stunted children.

Our final precondition of interest is parental education. In the results here, maternal education is a significant contributor to children's stunting status. Children whose mothers or fathers have a primary or secondary education are more likely to be nonstunted compared to those children who have mothers with no education. The results are similar for partner's education as well. Increasing food production does not produce more nonstunted children for any educational attainment. Therefore, for children who have parents with little education, living in a community with more food or going through seasons where more food was produced does not affect their health in a positive direction. Selecting out the children with parents who are the most or least educated and comparing stunting outcomes based on food production also did not yield any significant results that would indicate that food production can mitigate educational differences related to stunting.

## Discussion and Conclusions

There are some important limitations to our research project, particularly relating to our data. One of the important limitations is that DHS does not include information on how long a child has lived in an area. We assume that the children have lived in the same area where they currently live for the duration of their lives. This assumption is probably more realistic among the rural dwellers and possibly the least realistic among the urban poor, where we might see recent arrivals from rural areas. Generally, in Mali, families with young children are not highly mobile and instead these families stay in communities where they have established support systems (this is highly culturally valued). Without accurate data on mobility, though, in some cases we might be inappropriately attributing community characteristics to specific children.

The second important limitation is our estimate of food production. Although this estimate is based on extremely thorough, detailed, and time-consuming remotely sensed data interpretation, we still rely on a statistical approximation of cultivated area in places where we do not have remotely sensed data. We acknowledge that an agricultural survey, for example, might provide more nuance into what is grown and exactly how much is grown for each household and community, but the reality is that data of that sort are not available at the spatial and temporal scale necessary for an analysis of this kind. In fact, no survey-based data exist that could be used in place of the remotely sensed data that we processed and employed for this analysis. Thus, although not ideal in some ways, the data used here do represent the best available data on small-scale food production for the entire country at relevant temporal scales. Future microlevel studies examining a selection of villages might be useful in enhancing scientific understanding of food production, health, and preconditions.

Contemporary discussions of global food insecurity, climate change, and children's health often present increasing food production (or food availability) as a possible solution to food insecurity and the accompanying childhood health challenges. In fact, increasing smallholder production is a key component of climate change mitigation put forth by government and nongovernmental organizations around the world. This research examined the impact of increased community food production on children's stunting with attention to some of the most commonly discussed preconditions of vulnerability to stunting. We specifically aimed to determine whether food production variability can inform scientific understanding of the ways in which food availability and individual-, household-, and community-level risk factors affect stunting outcomes in Mali. The results suggest that increasing food production can work to increase the number of nonstunted children in a community in some cases.

One of the notable results was that more food production had a positive impact on children who were already more likely to be healthy (nonstunted), specifically children from relatively wealthier households. Therefore, in terms of policy and nutrition outcomes, increasing food production might result in improved macrolevel health characteristics of a country or community, but this strategy could still leave the neediest and most marginalized children out. At the very least, increasing food production does not seem to solve the food access, availability, or utilization issues faced by the poorer children in a community.

Another outcome of the research was the importance of low birth weight as a precondition to stunting outcomes. The linkages among food production, low birth weight, and eventual stunting outcomes has not been explored and quantified in a developing world setting. Unfortunately, because of the small sample size, we concentrated on how infants born at a healthy weight progress to stunted status through food production, rather than our initial intention of healthy outcomes despite low birth weight beginnings. Although not able to model the same pathway or our initial focus, our results do give insight into the relationship among these three factors. In communities or during years where food production is lower, children are more likely to be stunted even when they were born at healthy weights and even in comparison to children who were born with low birth weight. Ultimately, more research on the pathways that lead from low birth weight versus healthy birth weight to stunting outcomes need to be explored, but our results do suggest that community characteristics related to agriculture might indeed be significant in a child's health outcome.

Finally, the results suggest that certain characteristics—namely, parental education and parental anthropometric characteristics—are significant and cannot be overcome with the addition of increased food production. In other words, children of parents without education are not likely nonstunted because of more food production but because of other factors not explored here. The same conclusion can be made for children of shorter mothers. When children have shorter than average mothers and they are not stunted themselves, the reasons for their nonstunted stature cannot be attributed to higher than average food production at the community level.

In terms of a theoretical contribution, the results specifically address some of the theoretical discussions of food insecurity and equal access to resources. In some senses, the models suggest that "the rich get richer" in terms of food production in their implication that the richer a family is, the greater access they have to food and the community resources required to produce food. Because rural Malian community land rights are most often decided by the chief of the community, consideration of how land use decisions are made and resources are shared is necessary to fully examine the relative importance of food access versus food availability.

With reference to policy interventions and food production, our results suggest that increasing food production at the community level might have some positive impact on some children but is not likely to be the primary solution to reducing rates of children's undernutrition in the developing world, at least not in very poor, rural countries like Mali. This outcome supports the findings of earlier, related work in Haiti (Mulder-Sibanda et al. 2002). Understanding what aspects of women's education contribute to healthy children should be explored more, perhaps in conjunction with increasing women's agency in terms of negotiating institutions—health care, food aid agencies, and so on. Further, appreciating the ways in which the poorest households procure, prepare, store, and distribute food might help unravel what makes children from these poor households so vulnerable to food insecurity even in the context of higher food production communities. In summary, increasing food production—a component of the food availability pillar of the conceptual model of food insecurity—does not fully address the food insecurity and health challenges facing the poorest children in the poorest countries of the world.

## Acknowledgments

We are grateful for the helpful suggestions and comments of the editor and the anonymous reviewers.

## Funding

This research was funded, in part, by NASA Grant NNX13AC67G. Kathryn Grace and Greg Husak were funded, in part, by USGS grant G14AC00042.

Kathryn Grace was also partially supported by NASA Grant NNX13AC67G. Nicholas Nagle's effort was funded by the National Science Foundation (NSF) grants SES-1132008 and BCS-0961294.

## Notes

1. In this case, care is the provision in the household and the community of time, attention, and support to meet the physical, mental, and social needs of the child (International Conference on Nutrition 1992).
2. Because of data limitations, we estimate food production with area under cultivation or cropped area. Because cultivated area provides an indication of food production, we use the terms interchangeably in the text. More details on variable construction are provided in the data and methods sections.
3. The four pillars of food insecurity provide a theoretical framework for analysis of the causes of food insecurity. Over time these pillars have been adapted and modified to reflect improved research and policy efforts relating to food insecurity. These pillars have been extensively explored in academic and policy literature and are well explained as a conceptual framework in work by Smith and Haddad (2000).
4. We define *resilience* as "the individual's predisposition to resist the potential negative consequences of the risk and develop adequately" (Engle, Castle, and Menon 1996, 2). In this case being healthy or nonstunted is considered developing adequately.
5. The term *positive deviance* is used to describe this analytic approach (Zeitlen 1991). A positive deviance model examines how and why some at-risk individuals ultimately come to healthy outcomes. Because it could have important policy relevance as it aids in developing strategies that individuals or families might already implement, this approach has been used in various types of health research.
6. There is very little research on how food is shared among community members in rural West Africa. Therefore, this assumption is based on anecdotal evidence including conversations with Malians and observations of the first author in other West African communities.
7. NDVI is a commonly used measure within remote sensing to measure the amount of vegetation growth (see Tucker 1979). NDVI captures the difference in reflectance of a pixel in near-infrared and red spectra. This metric evaluates the vegetation coverage within a pixel and has also been used to estimate crop production, land use and land cover, biomass, and numerous other applications (see Brown et al. 2014; Grace, Husak, and Bogle 2014). We use MODIS-based NDVI data based on the NASA Terra satellite (Justice et al. 1998; Huete et al. 2002).
8. Technically the variable is partner's education. We assume that the mother's partner is the father of the child.
9. The wealth index is constructed by MEASURE, the organization responsible for collection, processing, and managing the DHS data. MEASURE uses principal components analysis to evaluate and rank households based on assets and characteristics. Water source, television ownership, radio ownership, toilet facilities, and other factors are included (see Rutstein and Johnson, and ORC Macro MEASURE 2004).
10. The term *wealthy* is used here in a comparative sense and is based on the DHS classification. In most cases it would be inappropriate to assume that these households are wealthy in terms of finances or assets at a global level. Rather, the characterization of wealthy distinguishes the households that have a large number of assets compared to other Malian households.

## References

Abu-Saad, K., and D. Fraser. 2010. Maternal nutrition and birth outcomes. *Epidemiologic Reviews* 32 (1): 5–25.

Alderman, H., J. Hoddinott, and B. Kinsey. 2006. Long term consequences of early childhood malnutrition. *Oxford Economic Papers* 58 (3): 450–74.

Balk, D., A. Storeygard, M. Levy, J. Gaskell, M. Sharma, and R. Flor. 2005. Child hunger in the developing world: An analysis of environmental and social correlates. *Food Policy* 30 (5): 584–611.

Barrera, A. 1990. The role of maternal schooling and its interaction with public health programs in child health production. *Journal of Development Economics* 32 (1): 69–91.

Benjaminsen, T. A., and E. Sjaastad. 2002. Race for the prize: Land transactions and rent appropriation in the Malian cotton zone. *The European Journal of Development Research* 14 (2): 129–52.

Bhandari, N., R. Bahl, S. Taneja, M. de Onis, and M. K. Bhan. 2002. Growth performance of affluent Indian children is similar to that in developed countries. *Bulletin of the World Health Organization* 80:189–95.

Black, R. E., L. H. Allen, Z. A. Bhutta, L. E. Caulfield, M. de Onis, M. Ezzati, C. Mathers, J. Rivera, and the Maternal and Child Undernutrition Study Group. 2008. Maternal and child undernutrition: Global and regional exposures and health consequences. *The Lancet* 371 (9608): 243–60.

Boyle, M. H., Y. Racine, K. Georgiades, D. Snelling, S. Hong, W. Omariba, P. Hurley, and P. Rao-Melacini. 2006. The influence of economic development level, household wealth and maternal education on child health in the developing world. *Social Science & Medicine* 63 (8): 2242–54.

Bronte-Tinkew, J., and G. DeJong. 2004. Children's nutrition in Jamaica: Do household structure and household economic resources matter? *Social Science & Medicine* 58 (3): 499–514.

Brown, M. E., K. Grace, G. Shively, K. B. Johnson, and M. Carroll. 2014. Using satellite remote sensing and household survey data to assess human health and nutrition response to environmental change. *Population and Environment* 36 (1): 48–72.

Burgert, C. R., J. Colston, T. Roy, and B. Zachary. 2013. Geographic displacement procedure and georeferenced data release policy for the Demographic and Health Surveys. DHS Spatial Analysis Reports No. 7, ICF International, Calverton, MD.

Carroll, R. J., D. Ruppert, L. A. Stefanski, and C. M. Crainiceanu. 2006. *Measurement error in nonlinear models: A modern perspective*. Boca Raton, FL: CRC.

Cellule de Planification et de Statistiques (CPS/SSDSPF). 2012/2013. Institut National de la Statistique (INSTAT), Centre d'Études et d'Information Statistiques (INFO-STAT) Bamako, Mali et ICF International, Rockville, MD, USA.

de Sherbinin, A. 2011. The biophysical and geographical correlates of child malnutrition in Africa. *Population, Space and Place* 17 (1): 27–46.

Devereux, S., and J. Edwards. 2004. Climate change and food security. *IDS Bulletin* 35 (3): 22–30.

Doan, R. M., and L. Bisharat. 1990. Female autonomy and child nutritional status: The extended-family residential unit in Amman, Jordan. *Social Science & Medicine* 31 (7): 783–89.

Dyson, T. 1996. *Population and food: Global trends and future prospects*. London: Routledge.

Engle, P. L., S. Castle, and P. Menon. 1996. Child development: Vulnerability and resilience. *Social Science & Medicine* 43 (5): 621–35.

Engle, P. L., P. Menon, and L. Haddad. 1999. Care and nutrition: Concepts and measurement. *World Development* 27 (8): 1309–37.

Ericksen, P. J. 2008. Conceptualizing food systems for global environmental change research. *Global Environmental Change* 18 (1): 234–45.

Fishman, S. M., L. E. Caulfiedd, M. de Onis, M. Blössner, A. A. Hyder, L. Mullany, and R. E. Black. 2004. Childhood and maternal underweight. In *Comparative quantification of health risks: Global and regional burden of disease attributable to selected major risk factors*. Vol. 1, ed. M. Ezzati, A. D. Lopez, A. Rodgers, and C. J. L. Murray, 39–161. Geneva: World Health Organization.

Fotso, J. C., N. Madise, A. Baschieri, J. Cleland, E. Zulu, M. K. Mutua, and H. Essendi. 2012. Child growth in urban deprived settings: Does household poverty status matter? At which stage of child development? *Health & Place* 18 (2): 375–84.

Frongillo, E. A., M. de Onis, and K. M. P. Hanson. 1997. Socioeconomic and demographic factors are associated with worldwide patterns of stunting and wasting of children. *The Journal of Nutrition* 127 (12): 2302–09.

Frost, M. B., R. Forste, and D. W. Haas. 2005. Maternal education and child nutritional status in Bolivia: Finding the links. *Social Science & Medicine* 60 (2): 395–407.

Funk, C. C., and M. E. Brown. 2009. Declining global per capita agricultural production and warming oceans threaten food security. *Food Security* 1 (3): 271–89.

Glewwe, P. 1999. Why does mother's schooling raise child health in developing countries? Evidence from Morocco. *Journal of Human Resources* 34 (1): 124–59.

Godfrey, H., J. Beddington, I. Crute, L. Haddad, D. Lawrence, J. Muir, J. Pretty, S. Robinson, S. Thomas, and C. Toulmin. 2010. Food security: The challenge of feeding 9 billion people. *Science* 327: 812–18.

Grace, K., M. Brown, and A. McNally. 2014. Examining the link between food prices and food insecurity: A multi-level analysis of maize price and birthweight in Kenya. *Food Policy* 46:56–65.

Grace, K., G. Husak, and S. Bogle. 2014. Estimating agricultural production in marginal and food insecure areas in Kenya using very high resolution remotely sensed imagery. *Applied Geography* 55:257–65.

Grace, K., G. J. Husak, L. Harrison, D. Pedreros, and J. Michaelsen. 2012. Using high resolution satellite imagery to estimate cropped area in Guatemala and Haiti. *Applied Geography* 32 (2): 433–40.

Grace, K., and N. Nagle. 2015. Using high resolution remotely sensed data to examine the relationship between agriculture and fertility in Mali. *The Professional Geographer* 67 (4): 641–54.

Grantham-McGregor, S., Y. B. Cheung, S. Cueto, P. Glewwe, L. Richter, B. Strupp, and International Child Development Steering Group. 2007. Developmental potential in the first 5 years for children in developing countries. *The Lancet* 369 (9555): 60–70.

Gutbrod, T., D. Wolke, B. Soehne, B. Ohrt, and K. Riegel. 2000. Effects of gestation and birth weight on the growth and development of very low birthweight small for gestational age infants: A matched group comparison. *Archives of Disease in Childhood-Fetal and Neonatal Edition* 82 (3): F20814.

Habicht, J.-P., R. Martorell, C. Yarbrough, R. M. Malina, and R. E. Klein. 1974. Height and weight standards for preschool children: How relevant are ethnic differences in growth potential? *Lancet* I:611–14.

Haddad, L., H. Alderman, S. Appleton, L. Song, and Y. Yohannes. 2003. Reducing child malnutrition: How far does income growth take us? *The World Bank Economic Review* 17 (1): 107–31.

Haddad, L., and J. Hoddinott. 1994. Women's income and boy-girl anthropometric status in the Côte d'Ivoire. *World Development* 22 (4): 543–53.

Handa, S. 1999. Maternal education and child height. *Economic Development and Cultural Change* 47 (2): 421–39.

Huete, A., K. Didan, T. Miura, E. P. Rodriguez, X. Gao, and L. G. Ferreira. 2002. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment* 83 (1): 195–213.

Husak, G. J., M. T. Marshall, J. Michaelsen, D. Pedreros, C. Funk, and G. Galu. 2008. Crop area estimation using high and medium resolution satellite imagery in areas with complex topography. *Journal of Geophysical Research: Atmospheres (1984–2012)* 113 (D14).

International Conference on Nutrition. 1992. *Plan of action for nutrition*. Rome: ICN.

Joshi, A. R. 1994. Maternal schooling and child health: Preliminary analysis of the intervening mechanisms in rural Nepal. *Health Transition Review* 4 (1): 1–28.

Justice, C. O., E. Vermote, J. R. Townshend, R. Defries, D. P. Roy, D. K. Hall, V. V. Salomonson, J. L. Privette, G. Riggs, A. Strahler, and W. Lucht. 1998. The Moderate Resolution Imaging Spectroradiometer (MODIS): Land remote sensing for global change research. *IEEE Transactions on Geoscience and Remote Sensing* 36 (4): 1228–49.

Knops, N., B. B. Kommer, C. A. Sneeuw, R. Brand, E. T. M. Hille, A. Lya den Ouden, J.-M. Wit, and S. P. Verloove-Vanhorick. 2005. Catch-up growth up to ten years of age in children born very preterm or with very low birth weight. *BMC Pediatrics* 5 (1): 26.

Kramer, M. S. 1987. Determinants of low birth weight: Methodological assessment and meta-analysis. *Bulletin of the World Health Organization* 65 (5): 663–737.

Lobell, D., W. Schlenker, and J. Costa-Roberts. 2011. Climate trends and global crop production since 1980. *Science* 333:616–20.
Lopiano, K. K., L. J. Young, and C. A. Gotway. 2010. A comparison of errors in variables methods for use in regression models with spatially misaligned data. *Statistical Methods in Medical Research* 20 (1): 29–47.
Martorell, R. 1989. Body size, adaptation and function. *Human Organization* 48 (1): 15–20.
Mulder-Sibanda, M., F. S. Sibanda-Mulder, L. D'Alois, and D. Verna. 2002. Malnutrition in food-surplus areas: Experience from nutritional surveillance for decentralized planning in Haiti. *Food & Nutrition Bulletin* 23 (3): 253–61.
Mwabu, G. 2009. The production of child health in Kenya: A structural model of birth weight. *Journal of African Economies* 18 (2): 212–60.
Özaltin, E., K. Hill, and S. V. Subramanian. 2010. Association of maternal stature with offspring mortality, underweight, and stunting in low-to middle-income countries. *Journal of the American Medical Association* 303 (15): 1507–16.
Prince, A., and S. Groh-Wargo. 2013. Nutrition management for the promotion of growth in very low birth weight premature infants. *Nutrition in Clinical Practice* 28 (6): 659–68.
Pryer, J. A., S. Rogers, and A. Rahman. 2004. The epidemiology of good nutritional status among children from a population with a high prevalence of malnutrition. *Public Health Nutrition* 7 (2): 311–17.
Rodier, P. M. 2004. Environmental causes of central nervous system mal-development. *Pediatrics* 113 (Suppl. 3): 1076–83.
Rutstein, S. O., and K. Johnson. 2004. *The DHS wealth index. DHS comparative reports no. 6.* Calverton, MD: ORC Macro.
Semba, R. D., S. de Pee, K. Sun, M. Sari, N. Akhter, and M. W. Bloem. 2008. Effect of parental formal education on risk of child stunting in Indonesia and Bangladesh: A cross-sectional study. *The Lancet* 371 (9609): 322–28.
Sen, A. 1981. Poverty and famines: an essay on entitlement and deprivation. Oxford, UK: Oxford University Press.
———. 1999. *Development as freedom*. New York: Random House.
Smith, L. C., and L. J. Haddad. 2000. *Explaining child malnutrition in developing countries: A cross-country analysis* (Vol. 111). Washington, DC: International Food Policy Research Institute.
Steckel, R. H. 2008. Biological measures of the standard of living. *The Journal of Economic Perspectives* 22 (1): 129–52.
Strauss, J., and D. Thomas. 1998. Health, nutrition, and economic development. *Journal of Economic Literature* 36 (2): 766–817.
Thomas, D., J. Strauss, and M.-H. Henriques. 1991. How does mother's education affect child height? *Journal of Human Resources* 26 (2): 183–211.
Tucker, C. J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment* 8 (2): 127–50.
UNICEF. 1990. *Strategy for improved nutrition of children and women in developing countries: A UNICEF policy review*. New York: UNICEF.
Victora, C. G., L. Adair, C. Fall, P. C. Hallal, R. Martorell, L. Richter, H. S. Sachdev, and Maternal and Child Undernutrition Study Group. 2008. Maternal and child undernutrition: Consequences for adult health and human capital. *The Lancet* 371 (9609): 340–57.
Walker, S. P., T. D. Wachs, S. Grantham-McGregor, M. M. Black, C. A. Nelson, S. L. Huffman, H. Baker-Henningham, et al. 2011. Inequality in early childhood: Risk and protective factors for early child development. *The Lancet* 378 (9799): 1325–38.
Wood, S. N. 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society (B)* 73 (1): 3–36.
World Health Organization. 1995. *Maternal anthropometry and pregnancy outcomes: A WHO collaborative study*. Geneva: World Health Organization.
Young, F. W. 1994. The structural causes of infant mortality decline in Chile. *Social Indicators Research* 31 (1): 27–46.
Zeitlin, M. 1991. Nutritional resilience in a hostile environment: Positive deviance in child nutrition. *Nutrition Reviews* 49 (9): 259–68.

KATHRYN GRACE is an Assistant Professor in the Department of Geography, Environment and Society at the University of Minnesota, Minneapolis, MN 55455. E-mail: katqgrace@gmail.com. Her research highlights the role of context in various aspects related to maternal and child health with a particular focus on food insecurity and health issues in the Global South.

NICHOLAS N. NAGLE is an Assistant Professor in the Department of Geography at the University of Tennessee, Knoxville, Knoxville, TN 37996. E-mail: nnagle@utk.edu. His research interests include the production of small area population data and geospatial data fusion.

GREG HUSAK is the co-director of the Climate Hazards Group in the Geography Department at the University of California, Santa Barbara, Santa Barbara, CA 93106-4060. E-mail: husak@geog.ucsb.edu. His research focuses on improving the identification and monitoring of conditions leading to food insecurity in developing countries, particularly in sub-Saharan Africa.