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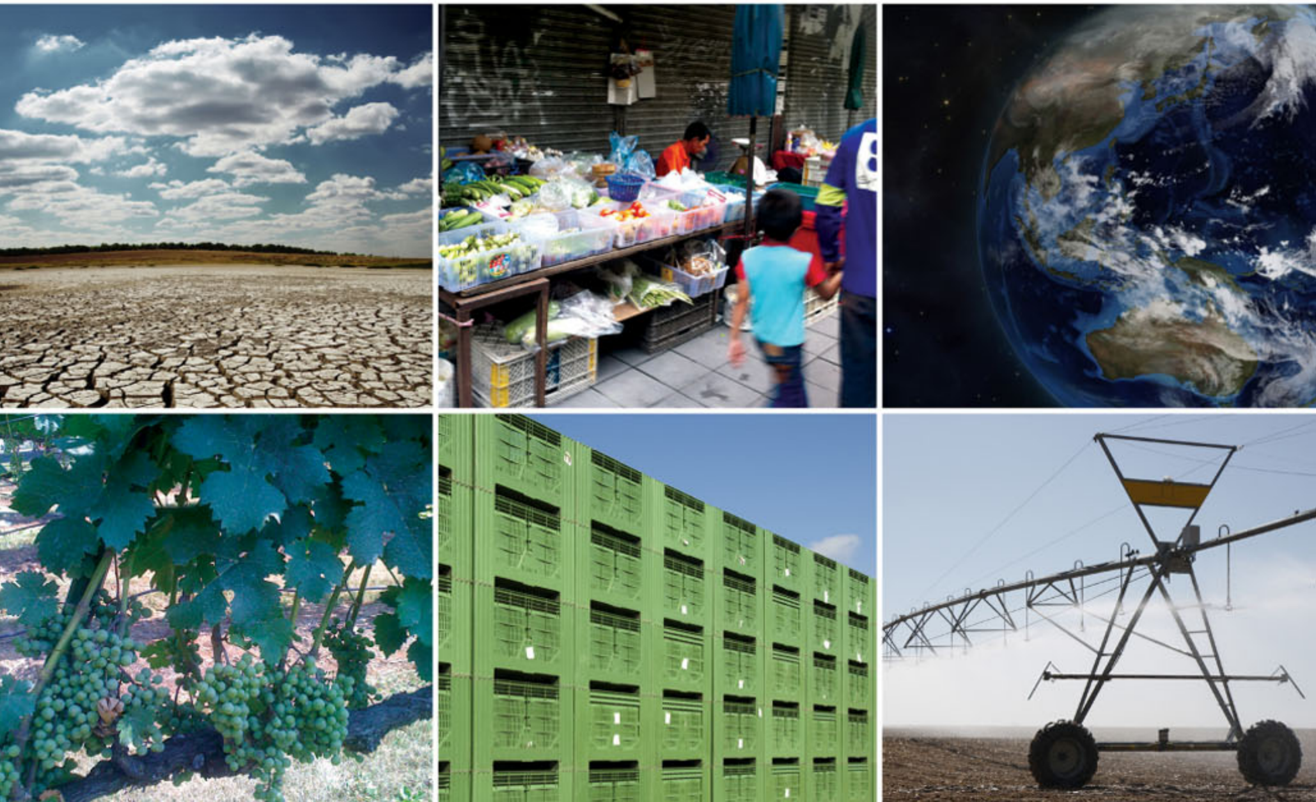
Molly E. Brown

Food Security, Food Prices and Climate Variability



FOOD SECURITY, FOOD PRICES AND CLIMATE VARIABILITY

The agriculture system is under pressure to increase production every year as global population expands and more people move from a diet mostly made up of grains, to one with more meat, dairy and processed foods. This book uses a decade of primary research to examine how weather and climate, as measured by variations in the growing season using satellite remote sensing, has affected agricultural production, food prices and access to food in food-insecure regions of the world.

The author reviews environmental, economic and multidisciplinary research to describe the connection between global environmental change, changing weather conditions and local staple food price variability. The context of the analysis is the humanitarian aid community, using the guidance of the USAID Famine Early Warning Systems Network and the United Nations World Food Programme in their response to food security crises. These organizations have worked over the past three decades to provide baseline information on food production through satellite remote sensing data and agricultural yield models, as well as assessments of food access through a food price database. These datasets are used to describe the connection and to demonstrate the importance of these metrics in overall outcomes in food-insecure communities.

Molly E. Brown is a research scientist at NASA Goddard Space Flight Center based in Maryland, USA. She has a BS in Biology, and an MA and PhD in Geography. Her research interests include understanding the effect of environmental variability on food prices and market functioning, and the use of satellite remote sensing for decision-making.

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Molly E. Brown

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ABBREVIATIONS

ANOVA	Analysis of Variance
AVHRR	Advanced Very High Resolution Radiometer
CEDAT	Complex Emergency Database
CFA	Central African Franc
CGIAR	Consortium of International Agricultural Research Centers
CRED	Centre for Research on the Epidemiology of Disasters
DHS	Demographic and Health Survey project and datasets
DRR	Disaster Risk Reduction
ENSO	El Nino Southern Oscillation
EROS	Earth Resources Observation and Science Center
FAO	Food and Agriculture Organization
FEWS NET	Famine Early Warning Systems Network
GDP	Gross Domestic Product
GPS	Global Positioning System
GIEWS	Global Information and Early Warning System
GNI	Gross National Income
GOES	Geostationary Operational Environmental Satellites
GPCP	Global Precipitation Climatology Project
GPS	Global Positioning System
IFPRI	International Food Policy Research Institute
IGBP	International Geosphere-Biosphere Programme
IPC	Integrated Food Security Phase Classification
IPCC	Intergovernmental Panel on Climate Change
MICS	Multiple Indicator Cluster Survey
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalized difference vegetation index
NGO	Non-Governmental Organization
NIR	Near Infra-Red Spectral Region

NOAA	National Oceanic and Atmospheric Administration
RMSPE	Root Mean Square Percent Error
SPOT	Système Pour l'Observation de la Terre (French remote sensing satellite)
TMPA	TRMM Multi-satellite Precipitation Analysis
TRMM	Tropical Rainfall Monitoring Mission
UN	United Nations
USAID	United States Agency for International Development
USGS	United States Geological Survey
VI	Vegetation Index
WHO	World Health Organization
WRSI	Water Requirement Satisfaction Index

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FOOD SECURITY, FOOD PRICES AND CLIMATE VARIABILITY

Introduction

High food prices are a concern for all families, but are particularly difficult for the poor who struggle to purchase enough food for their daily needs even when prices are low. For farming families, food prices affect household income as well as expenditures, since they grow food for sale as well as for their own consumption. Weather-related production variability is also a source of income uncertainty for farmers, and when food prices are high and production fails, these households will have particular difficulties obtaining enough food for three meals a day. In this book, the inter-relationships among food prices, food security and the variability of food production due to climate and weather are examined.

The Earth observation data record from satellites is now three decades long, providing robust, spatially explicit, high quality datasets that can be used to determine growing conditions across continents. Droughts, floods or other extreme weather events that affect agricultural yield and ultimately food production can be observed using satellite remote sensing data. Remote sensing uses instruments mounted on satellites or in planes to produce images or scenes of the Earth's surface, and is part of a suite of tools that provide up-to-date and quantitative information about land conditions to decision makers. These datasets serve as the basis for understanding trends and extremes of weather that impact the availability of food over large areas. Climate variability can be quantified by satellite data and used to estimate the likely impact on agricultural and economic systems.

Unusually or prohibitively high local food prices are a primary cause of food insecurity in the world. Information on food prices can enable diagnosis of market functioning, weather-related production shortfalls, and changes in accessibility of food across wide areas. These are all warnings of food security problems that policy makers should respond to, but may not be visible through other sources of information due to the complexity of the food system. Integrating climate-related shocks into food price analysis should be a new source of information for policy makers in their efforts to protect the most vulnerable from food security threats.

Climate variability is defined as seasonal, annual, interannual or several years-long variations in temperature and precipitation around an average condition defined over several decades. Climate variability can affect agricultural growing conditions both positively and negatively. As our climate changes, farmers will experience increased variability, with a heightened risk of both floods and droughts (Wetherald and Manabe, 2002; IPCC, 2007). Both positive and negative extreme events may affect agricultural production and therefore food security. Large-scale reductions in rainfall and food production across semi-arid regions of Africa were a proximate driver of the extreme food security crises of the 1970s and 1980s (von Braun *et al.*, 1998). Dramatic increases in food production over short periods without simultaneous improvements in transportation or market outlets may cause wholesale drops in food prices and rotting of excess grain in storage facilities, causing reductions in the income of small farmers (Sharma, 2013). Without anticipation of climate extremes, poor planning and inadequate policy response by governments in developing countries could exacerbate household food insecurity over large areas.

The World Food Summit of 1996 defined food security as existing when "all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life" (UN, 1996). Four conditions must be fulfilled simultaneously to ensure food security: food must be available, each person must have access to it, the food consumed must fulfill nutritional requirements, and access must be stable enough throughout the life of the person to ensure health. These elements are hierarchical and build on one another. Having food stocks in a region is not enough to ensure universal access to that food, and even if a household has access to available food, its members may be too sick to use the food effectively to attain an active and healthy life. Finally, availability, access and utilization of food must be maintained throughout the life of each person for food security to be achieved (Barrett, 2010).

Access to the food that is present in a community depends on the range of choices available to an individual or household, given the prevailing price of food, their income and the existing formal or informal safety net arrangements (Sen, 1981). When demand for food is stable, then access to food reflects the society's distribution of wealth and access to resources. When prices are high or change rapidly, the poor suffer the most since they spend most of their income on food and have no cushion against rising prices. The urban poor, who buy all their food, are particularly vulnerable. Food price spikes, or a rapid increase in the price of food over a few months, can have large and potentially irreversible impacts on social welfare, including impacts on health, nutrition, schooling, child labor and savings (Grosh *et al.*, 2008). Maintaining adequate consumption and defending assets in the face of rapid price increases can be enormously challenging for all except the most well off, particularly in countries whose populations already spend over half their income on food.

The price of food in a local market is determined by the supply of food as well as demand. Since everyone needs to eat every day, demand is fairly constant whereas supply can be widely variable, particularly in developing countries whose food production struggles to keep pace with demand. Since countries with large food insecure populations also are characterized by economies with large numbers of semi-subsistence farmers and small field sizes, widespread weather shocks to production can have a significant effect on the amount of food a country has to feed its population. Weather shocks impact the income of these farming households as well as their expenditures, increasing the demand for food in small local markets during a time of restricted supply. Even in normal years, local markets are susceptible to seasonality of the cereal supply (abundant after harvest, scarce during the growing season) and in the price of food (high during the growing season, low after harvest) reducing food security every year when farmers are using the most energy and need the most food.

Economic analysis of market price dynamics and market functioning is a critical part of how we understand the impact of weather extremes on food security. In many food insecure regions, small open-air markets function poorly and are isolated from capital city and international commodity markets. Expensive and inadequate rural transportation infrastructure, high transaction costs and inadequate legal frameworks contribute to low levels of participation in the market by many subsistence farmers. When local food production is affected by weather shocks, lack of well-functioning local markets severely reduces the ability of farmers to buy food from outside a weather-affected area at a reasonable cost.

Given the impact of food production and weather on the price of food, the need for integrated estimates of these are compelling. It has become increasingly clear that food security crises are far more related to market conditions than to weather shocks directly. If we can use models to understand the impact of droughts and other weather shocks on likely future price changes, we can amend food policies and craft better, more effective response to food security crises that are based both on markets and on agricultural dynamics.

Economic models can be used to characterize the impact of external shocks on local food markets and the communities that rely upon them (Kshirsagar and Brown, 2013). By characterizing the interaction between agricultural production and international prices on local food prices, our knowledge of how best to assess and respond to food security problems of communities across the world will be improved. This book explores the connection and interaction between climate variability, food prices and food security, using environmental information on the past three decades from satellite remote sensing to understand changes in food production and observations of food prices in small, local markets. Putting these datasets together using a quantitative model that exploits past observations, we can gain insight into the likely effect of future changes in climate and climate variability on food security in vulnerable regions.

Objectives

This book focuses on synthesizing basic research that describes the linkages among climate variability, food prices and food security in developing countries. The objective is to strengthen our understanding of the impact of climate variability on the price of food for vulnerable populations. Improved use of existing data by the early warning and humanitarian communities can make a big difference in how international organizations respond to food security crises.

By quantitatively connecting climate variability to food prices using a modeling framework, researchers and analysts can provide insights that will help early warning organizations recommend appropriate responses to high food prices and low food production. Developing a production–price model will allow early estimation of the impact of drought on food prices in markets as well as the likely geographic extent of these impacts. This book seeks to answer the following questions:

- How do climate variability and weather extremes influence local prices and access to food?
- Which food markets are most vulnerable to weather-related production shocks? Are these markets in regions with food security problems?
- How do global commodity prices impact local food prices and food security in a region?

- Can we use satellite observations to relate the biophysical response of plants due to climate variability to yield and overall food production?
- Do local food prices respond to agriculturally relevant weather shocks in food insecure regions?
- Can nutrition outcomes be linked to climate variability and food price volatility using data and analysis?
- What monitoring, analysis and policy changes are needed in the global humanitarian system to respond to the links between climate, weather and food prices in food insecure countries?

Geographic focus

Although the focus of the book is on global issues of food security, many examples and datasets are from Africa. Africa has the most widely documented severe food security problems, and has captured the focus of the international community. When drought occurs and food production suffers, local food markets in Africa are poorly supplied and the impact of these events can be seen in the food price time series. Because as a region, it has many governmental and non-governmental organizations working on alleviating food security problems, there is a lot of effort put into gathering and posting in publicly accessible databases food price information. Famine early warning systems are one of the primary actors in food security assessment and contribute to this work through the gathering and distribution of food price information in Africa.

Early warning of food security crises involves a chain of information communication systems that link observations of the determinants of food security to decision makers and then actors who can respond to those crises. The US Agency for International Development's (USAID) Famine Early Warning Systems Network (FEWS NET), the United Nations Global Information and Early Warning System (GIEWS) and other local, regional and national early warning systems work to provide timely and actionable information on food security crises to those whose responsibility it is to respond. These organizations routinely collect food prices and information on agriculturally relevant weather conditions, and assess the food security situation in affected communities. But they lack the analytical framework to link the information together in a quantitative way, since the links between weather and food prices can be obscure (Barrett and Maxwell, 2005; Brown, 2008a).

Plate 1 shows the extent of the global food price information currently available from the United Nations and USAID. Note that many of the time series, particularly outside capital cities, are in Africa. These datasets are gathered and distributed to improve response to food security crises, and thus are more comprehensive in regions where emergency food aid is more likely to be distributed. Regions with comprehensive, effective, government-led food price stabilization policies, such as India, Pakistan and China, are in general excluded from this book. Because the focus is the interaction between food prices, food security and climate variability, if food prices are artificially controlled, then different analytical methods from those presented here must be used to study the effect of production variability on household income and security.

Early warning organizations are a target for the research, approaches and analysis provided in this book. The author has worked with FEWS NET and has studied its methods and data for the past decade, and thus many of the examples and datasets used here are derived from the system. It is one of the best known and most influential of the early warning systems, and it works to move research from theory to practice rapidly when it has been shown to be of use (Brown *et al.*, 2007; Funk *et al.*, 2007; Husak *et al.*, 2013). The system and its partners are also the focus for potential adoption of the relationships and models explained here. If a better integration of biophysical and socio-economic drivers of food insecurity can be achieved, then more effective and timely information on the causes and appropriate responses to food security crises can be provided for decision makers seeking to respond to crises before they harm human welfare and development.

Income and food prices

Food prices are relevant to food security through their impact on constraining household food consumption when prices rise but incomes do not (Benin and Randriamamonjy, 2008; Brown, 2008b; Dangour *et al.*, 2012). Household incomes in developing countries are affected by many factors, including family size, number of employed or economically active family members, returns on investments and savings, and other factors. In many developing countries, rural household incomes are made up of many entitlements and assets that are not monetized, such as loans and gifts of food from relatives and friends, productive resources such as land, farm implements and seed stock, livestock, and natural resources in the public domain. Purchasing food on the market, however, requires cash, which is problematic to obtain if most of the household's assets are non-monetary. Households that grow food for their own consumption may have substantial assets such as land, farming equipment, livestock and housing, but converting these assets to cash will require a market or purchaser that is within the area where the farmer lives. During times of drought or crisis, farming households may grow only a fraction of the food they need for the year. If many farmers in a region are in need of cash because their crops also failed, the value of assets that can be sold to buy food will be affected because of a lack of demand (Sen, 1981). Simultaneously, the cost of purchasing food can increase substantially, reducing access to food across wide areas. This widespread, geographically coherent effect of weather on market prices can be anticipated with appropriate observations and models.

Food prices matter for food security outcomes since large proportions of households acquire some or all of their food from the market, even in good agricultural years (Godfrey *et al.*, 2010; Pinstrup-Andersen, 2009). Figure 1.1 shows estimates of average monthly household income in Burkina Faso derived from household surveys and expressed in 1993 dollars (Benin and Randriamamonjy, 2008), plotted with the average monthly price of 100 kg of millet for two cities, also expressed in 1993 dollars. The study showed that incomes were declining in Burkina Faso during the 1988 to 2007 period, while food prices were rising. Because the poorest segments of developing countries derive most of their income from the agricultural sector their incomes change only slowly, whereas the cost of purchasing food on the market changes rapidly. While land and water resources in Burkina are fairly static, the population is growing. Higher food prices have a short-term impact on national poverty, but have significant impacts on urban poor and rural households reliant on the market for their food (Minot and Dewina, 2013). These households are also significantly more likely to be food insecure in times of crisis.

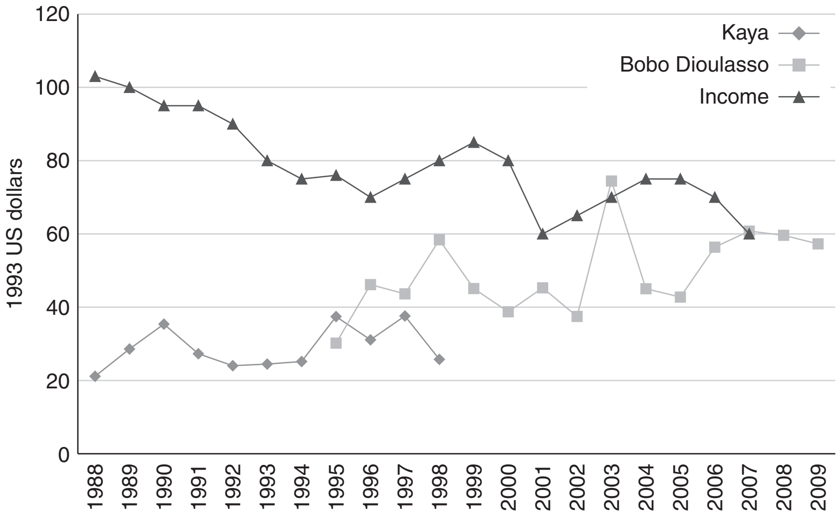

FIGURE 1.1 Average monthly millet prices per 100 kg millet and average monthly income in 1993 dollars in Burkina Faso (sources: monthly millet prices from Bobo Dioulasso and Kaya are expressed in 1993 international dollars and are from USAID historical price series, and the average monthly income data are derived from Benin and Randriamamonjy, 2008).

Food systems and vulnerability

Food systems are defined as the processes and infrastructure that are involved in meeting a population's food requirements. The activities involved in a food system are catching, growing, harvesting, storing, processing, packaging, transporting, marketing and consuming food (Ericksen, 2008). Economic conditions and a region's level of development affects how food production activities are conducted, and the weather, climate and environmental potential in the region affect how efficient these food systems are. Food security of households, communities and nations rely on food systems that enable enough food to be grown or imported from elsewhere to meet the needs of all residents.

Food price volatility, defined as the inability of market participants to predict food prices from one month or one year to the next, has a significantly negative effect on investment in the food system, food production and market efficiency. In many parts of the world, local food prices are independent of international prices because of their distance from and lack of interaction with the international market. Minot (2011) showed that only 13 of 62 local food price time series in Africa were influenced by world prices during a period when international commodity prices were changing rapidly. Other authors argue that government policies contribute significantly to local food price volatility, increasing uncertainty around food supply and imports from other regions (Tschirley and Jayne, 2010). Local weather shocks to production can be shown to affect local food prices, but may also contribute additional variability to an already poorly functioning market system (Zant, 2013; Ihle *et al.*, 2011).

When poor people rely on locally produced food for the majority of their caloric intake, shifts in climate and weather patterns such as drought can dramatically reduce local agricultural productivity, affecting how much food is available for consumption, trade or barter.

These variations in production, if sufficiently widespread and intense, can in turn affect the local price of food in isolated markets, since local demand rises while supply falls (Fafchamps, 2004). When most participants of an affected market are farmers with little cash income, lack of local purchasing power reduces the incentives of traders and others outside the region to supply the market despite increases in prices and potential profits. The subsequent reductions in the amount of food purchased and consumed by the poorest people in these areas can put millions of people at risk for malnutrition, particularly the young, old and sick who are more vulnerable (Darnton-Hill and Cogill, 2009). These and other factors besides overall quantities of food produced affect the price of food in small, developing region markets, including global cereal prices, fuel prices, transportation infrastructure, national policies, political stability and other influences (Swinnen and Squicciarini, 2012).

Because the concept of food systems includes both the socio-economic and the biophysical components of food security, it is very useful for assessing the impact of climate variability and change on food security (Ericksen, 2008). It also has a number of components that are not discussed here, including food safety, allocation across different members of a household, food preferences and food use, as well as the concept of the social value of food. This book is concerned primarily with broader, community-level food security assessment and the impact on food security of changing food prices in the context of humanitarian aid (Barrett and Maxwell, 2005; Brown *et al.*, 2009). Although the concepts of social value, intra-household distribution and food safety are critically important, they require fine-scale information that is often not available and therefore they are not incorporated into the framework that is presented here.

Communities that are food insecure may be significantly vulnerable to changes in the climate. Vulnerability can be thought of as a function of exposure to a hazard (e.g., lack of rainfall in a growing season month), sensitivity to the hazard (e.g., maize crop is at its emergent growing phase and needs water) and, finally, adaptive capacity in the face of the hazard (e.g., the ability of the farming household to replace the lost maize seed from other sources) (Ericksen *et al.*, 2011). If people have sufficient assets or strategies to manage a shock without suffering harm, then they are not considered to be vulnerable to that shock (McCarthy *et al.*, 2001). Exposure to changing climate patterns alone will not necessarily lead to increased vulnerability. Climate variability is just one more stressor on top of all the other economic and social factors that cause food insecurity (Nelson *et al.*, 2010). If climate causes significant reductions in food availability or raises food prices in the short term, the poor will simply eat less to compensate to avoid long-term degradation of their assets, resulting in harm to social welfare (Watts, 1981).

Analysis of the outcome of short-term reductions in food consumption usually occurs at the community level using outcome indicators regarding nutrition (percent of underweight children under five, body mass index of women of child bearing age, etc.). These indicators do not describe the underlying processes that contribute to malnutrition, such as chronic poverty, disease or lack of access to diverse and nutritionally adequate diet (Ericksen *et al.*, 2011). To analyze these factors, the level of analysis must move from the region and community level to the individual and household level using household survey information. By focusing on individuals and households, a much more nuanced view can be gained of the impact of weather shocks and food price increases on vulnerable communities (Johnson *et al.*, 2013). There is much to be gained by examining these data, and thus in this book we examine household survey information to understand the likely dual effect of food prices and climate variability on nutrition outcomes.

Poverty and food prices

Poverty, which can be defined as those households that have insufficient resources to maintain adequate food consumption for all members for all meals, is the primary cause of food insecurity (Ravallion, 1998). In 2012 there were 870 million people in the world who did not have enough to eat, the vast majority of whom (98 percent) live in developing countries where 15 percent of the population is undernourished (FAO, 2012b). Many of these hungry people live in poor countries that have been encouraged to move their economies away from subsistence agriculture to either cash crops or a more industrial base (Bryceson, 2002; UNCTAD, 2012). Global investment in agriculture in developing countries has declined since the 1980s, falling from 18 percent to just 4 percent in the mid-2000s (OECD, 2007). After increases in commodity prices in 2008 boosted profits for export-oriented agriculture, investment has rebounded significantly, but precious time has been lost. If investments had been made to increase the productivity of the millions of poor and subsistence-level farmers during the 1980s and 1990s, then the vulnerability of these countries to higher food prices that we are currently experiencing would be far less. Countries that are highly dependent on food imports are far more vulnerable to food price shocks than if they produce more of the food they consume (Moseley *et al.*, 2010). Countries that have inadequate foreign cash reserves to pay for sharply increased food imports during periods of rapidly increasing commodity prices are vulnerable to potential reductions in food supplies. Poor people who live in countries that do not have well-functioning social safety nets, trade policies or strategic food reserves to reduce the impact of these price shocks are even more vulnerable (Gouel, 2013; Grosh *et al.*, 2008; Cavero and Galián, 2008).

Volatility and wholesale increases in local food prices have a negative effect on the amount of food that families can afford to consume. Without prior planning for large increases in food budgets, families simply have no choice but to reduce consumption when basic food prices double over short periods. Households that already devote a high proportion of their income to food before the price increase occurred are particularly at risk (Figure 1.2). The lower the total income of a country, the higher the proportion of total expenditures is spent on food (Trostle *et al.*, 2011; von Braun, 2008). Countries like Kenya whose citizens already spend nearly 50 percent of their total disposable income on food cannot easily find additional resources to maintain consumption. A significant increase in food prices would affect the ability of a large proportion of the population to buy enough food for their families, if no assistance were available.

Globally, the proportion of income spent on food varies from the United States at 6 to 7 percent and Europe at 10 to 15 percent to Kenya at 50 percent (World Bank, 2013). Some regions of Niger have households that expend 60 to 70 percent of their income on food (FEWS NET, 2011). Regions with very high proportions of their income spent on food are more vulnerable to increases in prices on goods available in local markets.

The relationships between food prices, wages, patterns of agricultural production and income distribution are very complex. Climate variability affects food prices, but also the broader agricultural economy, availability of wage labor, cost of goods, marketable surpluses from previous years, risk of production and other relationships (Mellor, 1978). Remote sensing information can help us quantify the effect of environmental shocks on production, reducing one source of uncertainty in the economic analyses. Local food price volatility can be measured, and the next section describes the results shown from an analysis conducted by Minot in 2012.

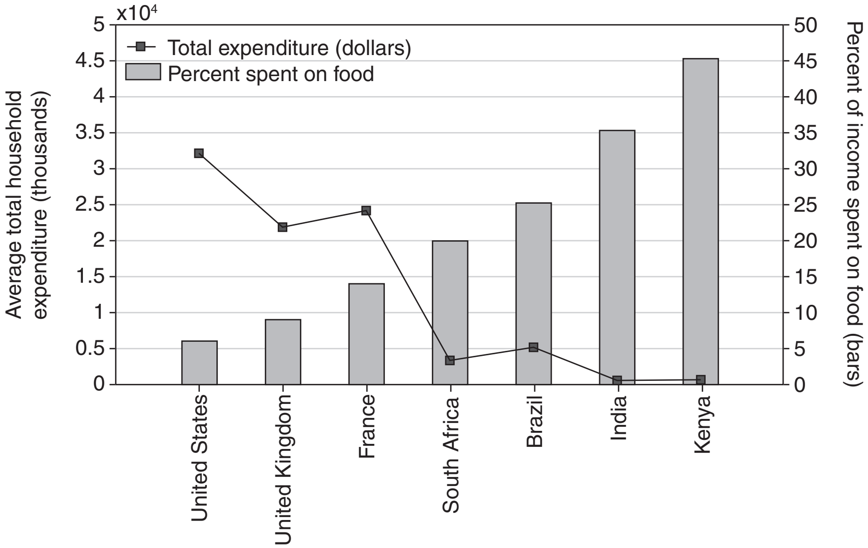

FIGURE 1.2 Average total household expenditures and percent of expenditures spent on food for seven select countries (source: data from World Bank, 2013; Meade, 2011).

Food price volatility and recent changes

In this volume, the term "volatility" will be used as a synonym for unpredictability. Although the term is often employed in the news media and in policy circles, its meaning is often not explained. Price volatility can mean changes in prices between markets, or may capture seasonal differences in prices that occur every year and are thus predictable. When food prices in a market increase significantly over short periods of time, it typically is caused by a decrease in local supply, an increase in local demand, an increase in the import and/or export parity price, or some change in government food policies. Since changes in demand for food are rarely large over short periods, changes in supply from unobserved causes are more often the source of the price change (Kshirsagar and Brown, 2013). Uncertainty in food prices is a cause for concern, since when producers, consumers and market intermediaries cannot accurately forecast cereal prices and consequently they are unable to make decisions regarding investment, savings and labor allocations, it creates significant economic impediments. Volatility also causes substantial short-term reductions in food consumption in households with low incomes or constrained access to resources. Thus food prices and their predictability are a critical element of food security analysis.

Changing food price levels

Regional price indices provide evidence of widespread increases in the base price levels in food insecure regions. Increases in the actual price of food are far more detrimental to food security than simply volatility (Barrett and Bellemare, 2011). Figure 1.3 shows five regional indices from FEWS NET that use locally relevant commodities, including sorghum, millet,

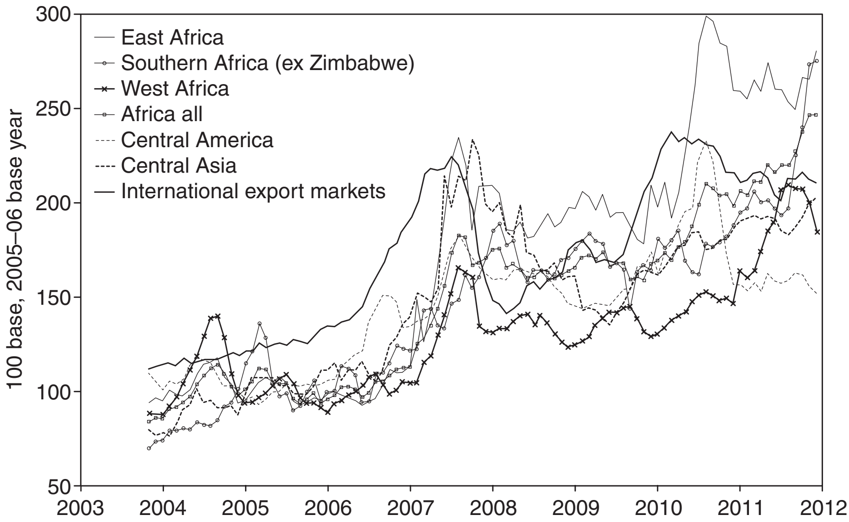

FIGURE 1.3 Regional food price indices, with the base year of 2005–06 set to 100 (source: FEWS NET food price database).

cowpeas, maize, potatoes, cabbage, carrots, onions, salt, rice, wheat, vegetable oil and other food stuffs. By broadening the price index beyond the traditional wheat, rice and maize, these food price indices are significantly more relevant to food security assessment (Brown *et al.*, 2012). The figure shows a doubling of these food security relevant food prices from the 2005–06 period (where the base value is 100) until the 2010–11 period. East African prices have increased even more than the other regions due to the severe drought and food security crisis experienced in 2012.

Rising food prices have a number of implications for food security outcomes. Higher producer or farm-gate prices might mean that farmers are able to make more money on each kilogram of grain they sell to the market, increasing their income over the short period. However, for households that fail to grow enough food for their consumption needs, rising prices harm their ability to purchase enough food on the market. If the cost of food increases more rapidly than income or entitlements through government transfers or loans, then many of the poorest people will be deprived of adequate food and malnutrition rates will increase. This connection between food security and nutrition outcomes will be explored in Chapter 2.

Questions that could be answered with research that integrates climate information into economic analyses include:

- How much of the food price increase seen in regions with food security crises was due to poor growing conditions over the past two years, and how much was due to international food price dynamics?
- Can we predict the changes in food prices over the next six months to ensure adequate humanitarian assistance is provided?
- How vulnerable are food insecure communities to climate variability and its impacts on production?

A model that quantitatively connects drought severity to changes in local food prices will enable a better understanding of which regions require intervention and which have adequate food supplies due to private market traders.

The food price shocks of 2008 showed the enormous vulnerability and exposure that many food insecure communities have to price volatility and level increases. The value of knowing whether food markets are working and the degree to which pre-existing vulnerability to food insecurity is affected by rising prices is of fundamental value. As our knowledge of the response of food markets to weather shocks at a variety of scales grows, we will increase our ability to identify, measure and understand the presence and impacts of significant changes in food access for the most vulnerable populations. Fundamental research will lead to new food security analysis tools that will support improved decision making.

Seasonal changes in food prices are also particularly difficult for households to cope with during periods of high price levels. Seasonality in food prices suggests that there is inadequate storage, insufficient production, low trade levels and/or high transport costs to move food from other regions (Handa and Mlay, 2006; Jones *et al.*, 2011; Alderman and Shively, 1996). Seasonality in the price of staple foods is a clear signal that the markets do not work well and that supply may not meet demand, causing much higher food prices during times of drought. A spatially explicit understanding of where weather shocks will be most important to food prices would greatly improve the ability of early warning organizations to respond to crises. Long-term planning and improved investment in infrastructure and other measures to improve market functioning may be critical for reducing vulnerability to future climate variability.

Assessing food security and nutrition outcomes

Over the past five decades, food security analysis has focused on understanding the measurable components of food supply at the national level (USDA, 2013). In developing countries, a large part of the population lives in poverty. Countries with extremely poor populations may have inadequate food supplies at the national level, leaving portions of the population without enough food, even if the food available was distributed evenly among all citizens. This is a problem of food availability. For decades, food balance sheets have been used to estimate how much of each food commodity a country produces, imports and withdraws from stocks for other non-food purposes. The analyst then divides the energy equivalent of all the food available for human consumption by the total population to calculate average daily energy consumption (FAO, 2012a). The problem with this type of country-level assessment is that it assumes that food availability is the primary cause of hunger and ignores the complex interactions between economics, food prices and entitlements that were described by Amartya Sen in his landmark publications (Sen, 1990, 1981).

Food security is often a problem in households that have insufficient income to purchase enough food for all members every day, even when there is more than enough food supply to feed everyone in a country if distributed evenly. This is a problem of access, where incomes do not meet required outlay. A variety of concepts and methods have been used to measure access to affordable and nutritious food, but these are part of a much broader assessment of the complex food system present in any country (Ploeg *et al.*, 2012). Figure 1.4 shows a typical national food security analysis operational framework, with the sectoral elements, thematic analyses and activities leading to various assessments and outlooks (Haan and Rutachokozibwa, 2009). The connection between the analysis and the decision making, shown at the

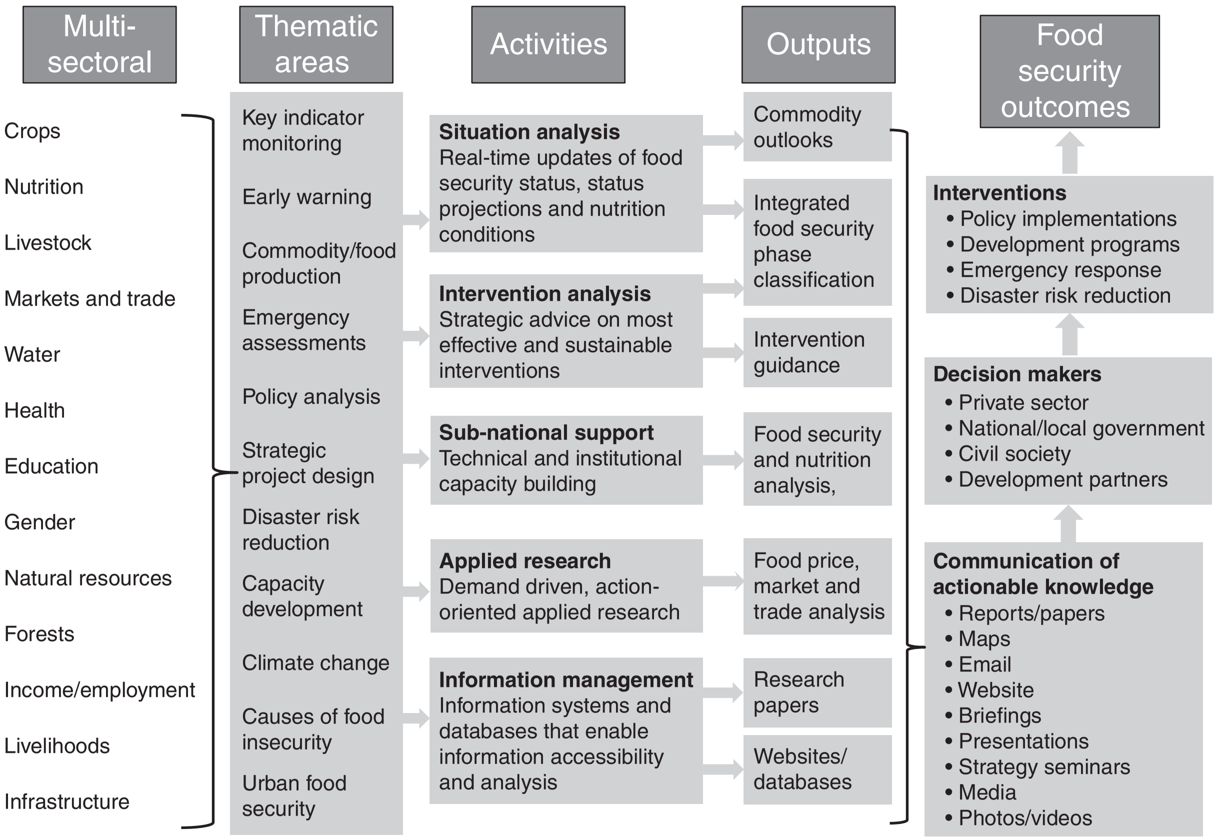

FIGURE 1.4 Multi-sectoral, thematic areas and activities that lead to analysis and improved food security outcomes in Tanzania (source: derived from Annex 4 of Haan and Rutachokozibwa, 2009).

right, at the national and international scale is tenuous and can be highly dependent on the geopolitical status and relationships of the nation to the donor community (Barrett and Maxwell, 2005).

Characterizing food access can be difficult because of the breadth of sources of both more nutritious and less nutritious foods and the complexity with which consumers make choices about where to shop, what to eat and how much time to devote to these and other food-related activities. Developing a quantitative assessment of food consumption involves estimating the number of eating occasions, documenting dietary diversity and estimating the percentage of households consuming minimum daily caloric requirements (Swindale and Ohri-Vachaspati, 2005). Connecting consumption to access instead of to overall food availability can also be challenging.

Diagnosing problems of access is often done with the price of food in a particular market or region. Early warning organizations monitor food access at the market system level instead of the household level, using information from retailers, wholesalers, transporters, infrastructure and financial services. The influence of the local policy environment is also assessed, describing the government's role in responding to the price and availability of food in the region. Some examples of important market characteristics that are monitored are commodity market networks, assessments of market integration, the geographic and economic distribution of food commodities, capacity of storage facilities, seasonal road conditions, national and import/export policies and cross-border trade.

Many food security indicators seek to incorporate measures of food access and nutrition as well as availability. The Global Hunger Index (GHI), for example, combines three equally weighted indicators: (1) the proportion of the undernourished as a percentage of the population (as measured by the FAO food balance sheet); (2) the prevalence of underweight children under the age of five; and (3) the mortality rate of children under the age of five (IFPRI and Welthungerhilfe, 2006). The focus is on the nutrition of children under five instead of a comprehensive sampling of society because all children should grow at the same rate before the age of five despite their genetic disposition to be taller or shorter, larger or smaller. Deficits of food and nutrients in children are thus more easily detected before this age and the long-term effects of these deficits last a lifetime (Darnton-Hill and Cogill, 2009). The weakness of the GHI is its lack of an adequate conceptual framework that allows policy and economic drivers to affect outcomes based on nutrition of children. In the context of climate variability, identifying policies that provide for effective response to extreme events is critical.

Food security analysis is becoming more focused on nutrition outcomes instead of solely on food availability, linking observations of the well-being of children from household surveys to the more traditional food balance approach. The challenge of these indices is that although food balance sheets can be calculated annually shortly after the main harvest, collection and analysis of nutrition information for children must be done household by household in a survey setting. Thus the information usually is not available until a year or more after the data has been collected. Moreover, the process requires a large and coordinated effort to conduct surveys in all countries, ensure data quality and obtain comparable data (Macro, 2013). Thus the GHI and other similar indices can be created only every five years or more and represent an assessment of the consequences of long-term food security problems, not acute emergencies. It cannot be used for early warning of increasing food security problems or to ensure timely humanitarian aid during times of crisis (Hillier and Dempsey, 2012).

Because food consumption is difficult to measure, estimates of access have been based on the difference between the price of food and the income of consumers. Rapid changes in the price of food can be used to understand changing access to food due to market factors since income rarely keeps pace. Databases of the price of food that is actually consumed by the poorest people were developed after the 2008 food crisis, and early warning organizations have begun to report the current price, in US dollars and local currency, with a calculation of the percent change from the previous month, from three months ago and from the same time in the previous year (Eilerts, 2013). Thus food prices are becoming far more central to how food security analysis is conducted, and their impact on local food security far more widely recognized.

Climate variability and environmental observations

Climate variability describes the recent weather and trends in temperature and precipitation, including the fluctuations associated with large-scale natural climate phenomenon such as El Nino Southern Oscillation or ENSO. Extreme droughts and wet periods, due to the interaction of large-scale wind and sea surface temperature changes, are also referred to as climate variability. Decadal and seasonal shifts in wind patterns and sea surface temperatures in the Atlantic cause changes in hurricane frequency, for example. The dust bowl drought in the 1930s in the United States, usually attributed to climate variability, is another example of a persistent and extreme climate event caused by larger decadal climate processes.

The interaction between climate variability and climate change is uncertain, since the changes in mean climate and mean variability can occur simultaneously. For example, an increase in the mean temperatures will give more extremes, but may not result in higher variability. Climate change may result in higher variability as well as a changed mean (Plate 2). Both of these changes will result in more extreme events that will have negative impact on food production.

Extreme changes in temperature can be documented, but these extremes cannot easily be connected to a change in the mean temperature, the mean variance or both. Uncertainties in the rate of change of the mean also confound interpretation of changes in the variance, since all variance statistics are dependent on the basis of estimate, which is the mean (Meehl, 2007). Precipitation is even more complicated than temperature because it is often not normally distributed, and thus statistical descriptions of the variability of rainfall are more complex, particularly over shorter time periods of five to ten years. The impact of environmental variability and change on society is hard to estimate since concurrent and dramatic demographic, land use and economic transformations have taken place over the same period.

The analysis in this book uses to the extent possible the observational data record instead of a modeling framework to understand the impact of climate variability on food security. Unlike global or regional climate models, observations allow conclusions that are less susceptible to model assumptions and model error. Observations are at a wide variety of spatial and temporal resolutions, and enable the use of data appropriate to the analysis needs. Agricultural regions have fine-scale gradients in temperature and precipitation that can have a significant impact on growing conditions. Thus adequate spatial resolution is important for understanding the impact of growing conditions on agricultural production.

Remote sensing observations can assess the impact of weather on agriculture and other vegetation on the land surface. Repeat observations over decades can quantify the long-term degradation of environmental conditions due to changes in land use, ecosystem functioning and climate. Remote sensing assessments of agriculture and food production help to identify which fields are under cultivation in any one year (Husak *et al.*, 2008), drought conditions (Atzberger, 2013; Eklundh and Olsson, 2003; Jeyaseelan, 2003), fields being irrigated (Thenkabail *et al.*, 2005), land degradation in drylands (Evans and Geerken, 2004), and other longer-term trends that result from anthropogenic activities (Turner *et al.*, 2003). These observations form the basis of food security assessment and are fundamental to our understanding of the impact of weather and climate change impact on food systems (Vermeulen *et al.*, 2012).

Linking food prices and food security

Using models that link environmental variability as measured by satellite remote sensing to food price dynamics, quantitative assessment of the likely impact of environmental change on food prices can be explored. It is possible to identify in a predictive way exogenous shocks to local food price dynamics. Modeling results described here show that local food price changes can be predicted in 87 out of the 179 locations where there were at least five years of monthly food price observations. Of the 87 locations, 59 were significantly influenced by domestic weather shocks as measured with satellite remote sensing between 2008 and 2012. The modeling framework shows the vulnerability of these small, local food markets to production shocks due to the weather, and the urgent need for investments to increase efficiency and reduce transaction costs in local markets (Zant, 2013), modernization of food production to boost yields in good years (Hansen *et al.*, 2011) and increased participation by farmers in markets to ensure supply.

The price of food in local markets is a critical indicator of food security and offers a better early warning of food scarcity. Without a clear understanding of current and projected market conditions, food security analyses will be incomplete and inadequate. If rainfall in a particular area is likely to be poor and food production negatively affected, using knowledge of market networks can help identify the geographic areas with and without access to alternative supplies and thus more precisely define the most affected areas. Those most affected could be situated outside the drought-affected region because of trade patterns. Focusing on just the immediate area could seriously underestimate the number of food insecure households and completely overlook areas that are potentially in need of assistance. Using a model that links weather shocks to local food price changes has the potential to provide immediate and useful information currently not available to early warning organizations.

Seasonality in the price of food is a critical source of information about the vulnerability of a region to climate variability. The seasonal increase in food prices in many isolated, small markets is due to the lack of storage capacity and to limited access of rural producers to export channels (Becquey *et al.*, 2012; Hillbruner and Egan, 2008; Brown *et al.*, 2009). Access to food from regional and international markets when prices are high is extremely limited in these areas due to the limited purchasing power of the region and high transaction costs (Brown *et al.*, 2012). Thus pre-harvest grain prices are significantly greater than post-harvest grain prices in many markets. This seasonality of food prices is used in this research to indicate a poorly functioning market, and to indicate that growing conditions will likely be more important for food price determination in that market than elsewhere.

Markets and the price of food shed light on two aspects of food security: whether there is food available in a region and the ability of people to access that food. Food supplies can be monitored in markets, for if a market is unusually poorly stocked or food prices are abnormally high, problems of both access and availability may be occurring. Access-related food insecurity is becoming increasingly prevalent with poor households reducing food consumption during times of seasonal scarcity even during years of above average food production and economic growth (Eilerts, 2006; Darnton-Hill and Cogill, 2009). Food security analysis that uses food prices and production information can evaluate in a more comprehensive way the impact of simultaneous income reductions and increased expenditures on food for rural households and the urban poor.

Food security analysts need to know whether the price of food in a market is unusually or prohibitively high for a particular set of households. Market analysis can help determine when particular events or conditions prevent participants in a market from releasing food stocks or moving commodities from one place to another. Food prices can provide information on production shortfalls, increases in the price of food and inputs, falling agricultural output prices, distress sales of livestock (e.g., sales of breeding stock or draft animals), uncharacteristically early movements of prices or large migration of people in search of causal employment. These are all warnings of food security problems that should be reported, but may not be visible through other sources of information.

FEWS NET's markets guidance handbook describes market information and analysis, and how they contribute to food security analysis. Such information and analysis:

- deepens our understanding of food security;
- adds temporal dynamic to food security analysis;
- links households to local, national, regional and global economies;
- highlights important national and regional spatial relationships or linkages;
- allows more precise estimates of humanitarian and development needs;
- improves scenario and outlook development and monitoring;
- clarifies appropriate type, magnitude and timing of response; and
- sheds light on the constraints to food security caused by market irregularities and inefficiencies (FEWS NET, 2009).

Information on food prices and the functioning of markets in which they are measured is needed to anticipate potential market stresses, constraints and responses in order to foresee the household response to these changes.

One way food price information is used in food security analysis is with an assessment of market integration. Market integration is a measure of the trading behavior, information and price differential between markets. A food security analyst is interested in knowing if there is physical trade of goods between markets, obtaining an evaluation of whether the difference in prices between two markets is about equal to the cost of transporting goods between the markets, and determining whether the prices in two markets tend to move together over time (FEG, 2013). Unfortunately, assessing integration of two markets quantitatively requires a lot of information rarely available in developing countries. These include the local price of fuel, transaction costs, transportation costs, government policy context and actual demand from consumers in the market (Goletti and Christina-Tsigas, 1995). Since locally explicit, regionally accurate information about markets in developing countries is rarely available, integration is often inferred from qualitative examination of price time series instead of quantitative analysis (Brown *et al.*, 2012).

After the 2008 global food and fuel price spike, FEWS NET gathered for general distribution a large set of food price data points in regional markets in food insecure countries that were updated in near real time every month. This dataset was then presented in a report that provides information on price movements in major markets for most of the 23 countries covered by FEWS NET. The report provided the current price in US dollars as well as the local currency, with a calculation of the percent change from the previous month, from three months ago and from the same time in the previous year. The bulletin has increased the visibility of market information in food security analysis, and the dataset forms the basis for research that seeks to provide real time assessment of the impact of environmental shocks on market prices. The practice of reporting on food price levels and changes in prices has been adopted by all international, regional, national and non-governmental food security organizations, and is used to detect, measure and prioritize the humanitarian response to populations affected by changing food prices (Eilerts, 2013).

Although the continuously updated food price database available to all on the FAO website is an important step forward for humanitarian aid organizations, there is a long way to go before food prices are fully integrated into efforts to monitor weather and international shocks on food security. FEWS NET and the United Nations World Food Programme monitor the impact of climate on food production through national production statistics and assessments, remote sensing assessments of agriculturally relevant rainfall and temperatures, and trade in agricultural inputs such as fertilizer and fuel for moving goods post-harvest. These information streams are currently independent and little effort is made to quantitatively assess the response of food prices to changes in production. By providing quantitative links and conceptual connections, this book may contribute to improvements in how price information is used in assessing and responding to crises.

Overview and structure of the book

This chapter has focused on providing an overview of the issues and concepts that are key to understanding food security, highlighting the role of local markets and climate variability in production and income. Satellite data and other sources of environmental information have the benefit of being spatially explicit, so the impact of bad weather on agricultural production can be assessed remotely and immediately. The chapter also provides a description of how models and quantitative analysis of local weather anomalies and market price response to changes in food supply could be used in food security analysis. Understanding these connections will help build improved early warning systems, design appropriate responses and build improved policies to reduce the impact of high and volatile food prices.

Chapter 2 provides an overview of the global food security assessment framework and how food prices and weather shocks are conceptualized within the system. It also describes famine early warning systems and their very specific data sources, needs and evidence requirements. The chapter outlines livelihoods and the impact of weather shocks on income, using an example of a livelihood analysis from Niger, one of the world's poorest and most food insecure countries. The chapter ends with a description of the data and information needs of famine early warning systems and how data is used within the system.

Chapter 3 discusses climate variability, including how we determine whether the environment is changing. It also examines trends in precipitation and temperature, as well as our ability to identify these trends both in models and in observations. Satellite remote sensing of moisture conditions that may affect food production, combined with long-term observations that enable an understanding of how ecosystems are changing, form the underpinning of the knowledge of climate variability. Remote sensing of vegetation is the primary source of information used to bring together information about weather shocks on food prices because of the observation's ability to integrate the impact of both temperature and precipitation on agriculture, and because of the independence of the measure from ground observations. These observations are described and their assessment of climate variability discussed.

Chapter 4 describes trends in national food security and the impact of climate variability and change on the ability of food insecure countries to meet their own food needs. Food security crises can be caused by structural problems, where food production languishes due to lack of investment, but development efforts do not provide adequate alternative sources of income for a growing population. When countries experience widespread production impacts due to drought and are unable to import and distribute sufficient food to meet the needs of its population, food security crises occur. This chapter outlines these vulnerabilities and describes efforts to understand long-term trends in agriculturally relevant weather that are likely to impact food security.

Chapter 5 summarizes trends in food prices and price volatility over the past decade. Because food price levels are at historic highs, the vulnerability of nations, communities and households to price dynamics is becoming much clearer. The chapter discusses trends in the number of people who are food insecure and the impact of high price levels on these people. It also explores the effect of international prices on local food prices, along with the impact on nutrition outcomes that changes in price levels are likely to have.

Chapter 6 focuses on seasonality. Thin, isolated and poorly functioning food markets are likely to exhibit food price seasonality, where prices are typically much higher during the pre-harvest season than the post-harvest season. A high proportion of the income of households in many developing countries is spent on food; thus, these seasonal increases are likely to affect nutrition outcomes as well as the debt burden and resource accumulation of households. The chapter also explores the link between regions with price seasonality and climate variability.

Chapter 7 presents research that quantitatively connects food price dynamics with observations of climate variability using satellite remote sensing in a predictive econometric model. It presents the underlying economic theory using supply and demand curves, and describes market functioning under different environmental conditions. Using a Kalman filter approach, maize prices from Africa are decomposed into a seasonal, trend and noise component and each is analyzed for its connection to environmental drivers. The model is used to demonstrate the impact of climate variability on price dynamics and the reduction in error due to the use of satellite observations.

Chapter 8 describes nutrition impacts of climate variability and environmental change. It explores the broader connections between environment and health outcomes, because although we can quantify the direct impact of drought and other weather shocks on food prices, there are many other pathways through which climate dynamics can affect food security outcomes. This chapter presents current and ongoing studies using Demographic and Health Survey information that measures directly the nutrition status of children and others in vulnerable communities.

The final chapter presents conclusions and policy relevance of an improved understanding of climate variability, food prices and food security interactions. It reviews government responses to food price spikes and their likely ability to incorporate new information on the interaction between prices and production. Climate variability is likely to continue to impact global agricultural markets through increasing droughts and temperature extremes. Innovative solutions and approaches to improving the resilience of vulnerable households are presented, along with conclusions and ways forward for early warning organizations.

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2

FOOD SECURITY AND MONITORING SYSTEMS

Chapter objectives

This chapter's objectives are to define food security and describe how food security crises are identified and anticipated. Trends in food production and food security are discussed at the community, national and international scales. A conceptual framework is provided that links climate and economic shocks to income and food consumption, providing ways that food security can be monitored. Income and entitlements play a central role in the development of and response to food security crises. Then the chapter describes USAID's Famine Early Warning Systems Network and how it monitors food security through the use of information and analysis on agricultural activity, the price of food and international trade is provided, along with an example from Niger. A description of the datasets that are needed to understand food security is provided and along with an assessment of how food prices fit into the analysis. Finally, the last section provides a critique on the connection between early warning and early action.

The elements of food security

Food security is defined as the ability of all people, at all times, to have the physical, social and economic access to sufficient, safe and nutritious food to have an active, healthy life (United Nations, 1948; G8, 2009). This high standard includes both the current situation as well as future vulnerability to changes in food security status (Barrett, 2010). A huge amount of information is needed to monitor who is food insecure, where they live and the causes of malnutrition, which covers a broad number of disciplines, including meteorology, agriculture, economics, politics, trade and many others. Global food security for all has not been attained for many reasons, including issues of poverty, natural resource disparities, unequal global trading arrangements and poor or corrupt governments.

The 1996 United Nations' World Food Summit defined food security as existing "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life." Both physical and economic access to food that meets people's dietary needs as well as their food preferences are included in the concept of food security. There are four conceptual elements to food security, which include:

- the availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports (including food aid);
- access to food by individuals with adequate resources for acquiring appropriate foods for a nutritious diet;
- the utilization of food through adequate diet, clean water, sanitation and health care to reach a state of nutritional well-being where all physiological needs are met; and
- the stability of these elements, in that to be food secure, a population, household or individual must have access to adequate food at all times. They should not risk losing access to food as a consequence of sudden shocks or cyclical events.

The concept has a hierarchical dimension, where food availability is a necessary but not sufficient requirement for access to food, and adequate utilization is required to obtain food security after one has access. Availability is often analyzed at the country or regional scale, access at the community scale and utilization at the individual scale, and is often defined as being part of health and health care, and less that of food security (Barrett and Lentz, 2010) (Figure 2.1).

Adequate food availability is the cornerstone upon which food security rests, as consuming sufficient macronutrients (carbohydrate, fat and protein) is required for health and well-being. Although for most of human history, lives were short and unhealthy because of lack of adequate food, beginning in the eighteenth century a succession of countries was able to provide the entire population with adequate food, transforming both individual health and the economy of the region, enabling a great increase in economic productivity (Fogel, 2004). By the twentieth century, nearly all communities and countries were able to provide adequate

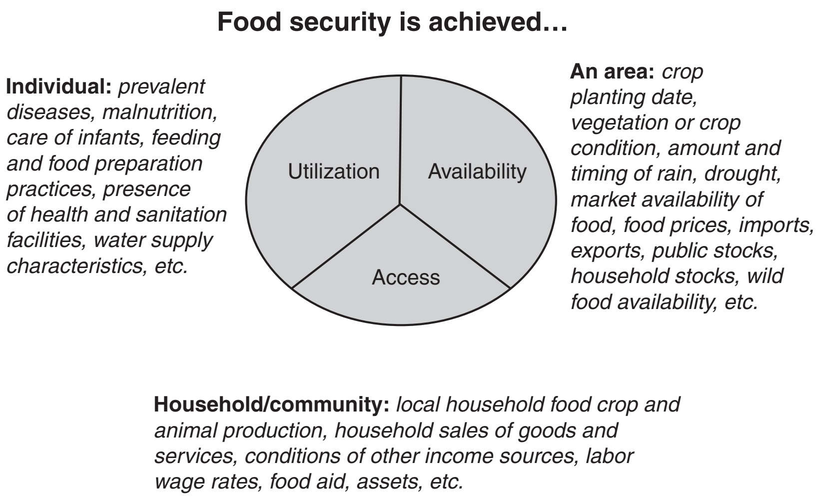


FIGURE 2.1 Food security is made up of the utilization, availability and access to food, which can be assessed at the individual, area and community levels of analysis (source: Gary Eilerts).

food for its citizens and food insecurity became a problem of poverty due to inequality of access. Recent research has shown that malnutrition may lead to a significant change in intestinal microbial communities, which is likely to increase susceptibility to infectious diseases and immunodeficiency (Izcue and Powrie, 2012). Similarly, when children under the age of five are exposed to large amounts of infectious material due to poor hygiene, the body diverts energy to its immune system, depriving the child of proper energy for growth and development leading to stunting (Lunn *et al.*, 1991).

Access to food requires that all individuals have the income sufficient to purchase food that is personally and culturally acceptable (Sen, 1981). The concept of access focuses on the ability of households to maintain food consumption in the face of a wide variety of shocks that increase the gap between available income and entitlements and the amount of food that can be purchased with that income at a particular time and place. These shocks include unemployment, loss of livelihood-producing assets, increases in food prices due to a localized drop in supply or increase in demand, and broader political or economic crisis which reduces entitlements to resources. Issues of access are described most clearly in social science concepts of individual and household well-being, which capture stress and coping strategies at a variety of scales (Barrett, 2010).

Because they are fairly straightforward to collect and are comparable across markets, food prices and the terms of trade between salable goods such as livestock and the staple grains are often used to monitor the ability of a community to access food. Understanding the causes of high food prices in any particular location, however, is important for ensuring that food security interventions are appropriate. High food prices can result in higher producer prices that can benefit farmers with surplus goods to sell, but harm net purchasers of food such as the landless poor and urban consumers (Swinnen and Squicciarini, 2012). The complex role of tariffs, taxes and import bans can cause locally grown food prices to change along with the availability of imported goods such as wheat and rice (Moseley *et al.*, 2010), changing the profitability of agriculture but also lowering the cost of food. Monitoring food production, food prices and food systems to better understand trade mechanisms will be increasingly important for anticipating changes in food access and what intervention may be necessary to respond to rapid changes in prices (FAO, 2011; Gouel, 2013).

Food utilization concerns the health of an individual or household, and their ability to utilize effectively the food they do have access to. Often defined in terms of the health of the individual, food security has recently expanded to include issues of both malnutrition and obesity resulting in the choice of foods that are affordable and have particular characteristics of the balance of nutrients, carbohydrates and fats (Eckhardt, 2006). Is food properly prepared and free of environmental contamination or water borne diseases? Are young children being fed an adequate diversity and nutritionally balanced foods? Issues of food utilization focus the community's attention on issues that undermine food security even in the presence of wider availability and access (Myers and Patz, 2009).

Finally, stability requires that availability, access and utilization are present throughout the life of a person. For vulnerable individuals such as children, the sick and elderly, even short-term reductions in food consumption due to problems of food security can lead to long-term impacts on cognitive ability, productive capacity or death (Alderman *et al.*, 2006; Mason *et al.*, 2003). Thus stability across months, seasons and years is an important aspect of ensuring positive outcomes for the poorest populations.

Causes and drivers of food insecurity

Figure 2.2 shows the cycle of governmental response and context in which production variability caused by weather shocks occurs using boxes that are linked with arrows, connecting poverty and high local food prices with household priorities, nutrition outcomes, adaptation, survival, economic growth and crisis. The framework seeks to put food security problems and resulting nutrition outcomes into the same picture as environmental and food price monitoring networks. Starting in the center, climate variability and anthropogenic drivers like land cover change and land degradation effect vegetation seasonality and rainfall, which impact food production directly and environmental change and agricultural vulnerability to weather drivers. Local food prices are affected by food production in that season as well as long-term potential production and other drivers such as commodity prices for food and fuel. Changes in food prices are associated with increases in poverty due to the pressure it puts on poor households' budgets, resulting in reduced food consumption or intake. Reduced food intake and increased food prices results in a change of priorities in households' budgets, leading to reductions in health care use, expenditures on education and reductions in psychological well-being. With less health care being used and reduced food intake, changes in nutrition outcomes are likely to occur, with increased stunting and wasting and reductions in infant birth rates in the short term.

Over decades, adaptation to scarce resources results in a falling life span, increases in morbidity and mortality of the population, and reductions in cognitive outcomes due to nutrition deficiencies in the first few years of life (Atinmo *et al.*, 2009, Martorell *et al.*, 1994). Long-term impacts on cognitive development and energy availability for physical labor will ultimately reduce the economic growth rate for the broader society (Grosh, 2008), resulting in economic crisis, which may also be driven by external factors such as high (low) commodity prices and agricultural inputs.

Although malnutrition is the result of widespread and persistent food security problems, humanitarian organizations work to intervene before nutrition problems are evident in the most vulnerable populations. Food security organizations tend to focus on providing analysis of the availability of food in an area, and access to food by households and communities, leaving the utilization factors to the health community. New research that links climate variability more directly to changes in nutrition outcomes is increasingly important to understand the impact of environmental change and ecosystem transformation on nutrition outcomes. The complexity of the interactions between the elements shown in Figure 2.2 dictate that more research is needed to enable policy development regarding the impact of climate variability on the system, and how perturbations will impact each aspect.

Food access, income and prices

Problems of access to food occur in all societies, but in developed countries there is a wide array of formal and informal ways to provide food when an individual or household does not have adequate income to purchase or grow it his or herself. Access to food through entitlements hinges on purchasing power and the ability of the poor to convert skills or labor power into cash that can be used to purchase food (Sen, 1981). When a large-scale crisis occurs that reduces the ability of a particular group of people to sell their skills or labor, reducing their income and consequently their ability to purchase food, a food security crisis can occur with no changes in food availability.

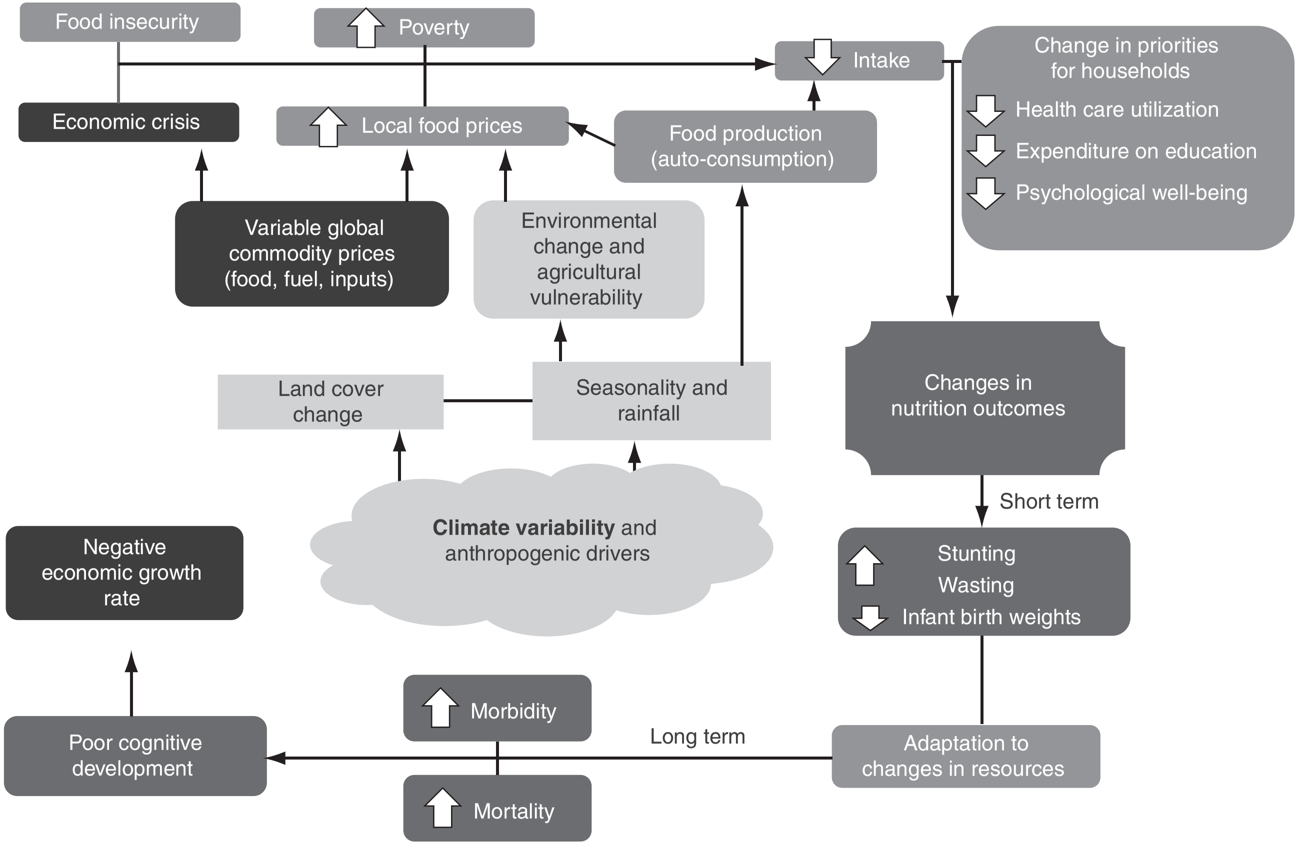


FIGURE 2.2 Conceptual framework that links climate variability and anthropogenic drivers to their consequences on food production to food prices (source: derived from Darnton-Hill and Cogill, 2009; Woldetsadik, 2011).

Note
Light grey boxes are observable environmental parameters, mid-grey boxes are household-level factors, grey boxes are individual factors and dark grey boxes are societal factors.

Social security or safety net programs that provide assistance to the poor include income assistance specifically focused on meeting the needs of these individuals to ensure that they get enough food to eat. The United States' Supplemental Nutrition Assistance Program or "food stamps" is the US government's approach to reduce hunger for the US poor. Food pantries give away groceries and shelters that provide three meals a day are also available for anyone who shows up without regard to income or identity. Such programs provide a basic safety net that can reduce or eliminate calorie-based malnutrition due to food access problems. Micronutrient deficiencies, however, is a more challenging problem, and can be found throughout the world, particularly in people suffering from obesity (Eckhardt, 2006).

Although problems of access are widespread, the physical lack of food occurs only very rarely, and usually only in regions experiencing prolonged conflict such as in Somalia. Food insecurity occurs not because there is a lack of food, but because a portion of a society cannot access sufficient food due to a personal lack of resources (Sen, 1981). The entitlement approach to food security includes four categories of entitlements:

- production based, or what you grow;
- trade based, or what you buy;
- own-labor based, or what you earn;
- transfer based, or what you are given.

These four entitlements together ensure that all people in a society get enough to eat to avoid starvation. The focus of entitlements is income and purchasing power that provides the ability of all households and individuals to buy enough food to maintain health and activity level (Pinstrup-Andersen, 2009).

There are some advantages of using information on food prices instead of data on income and entitlements to determine food access. Unlike information on a household's food consumption, there are consistent, comparable observations of the price of staple foods in specific markets around the world every month that can be used to measure relative changes in entitlements. If the underlying structure of poverty and food security remains the same in a society, but the price of food changes in a local market because of external drivers such as the weather or changes in the international price of food or fuel, then it can be inferred that there may be an effect on the poor households in that community (Schreiner, 2012). Direct information of household income and food purchases are complex, take months of interviews to obtain and years to publish and distribute (Macro, 2013). The information is available only for very limited areas over short periods of time. As Sen (1981) points out, income and entitlements are complex since many assets of poor people are not monetized and are bundled together in unique ways that enable them to access food. These commodity bundles are complex, vary across societies and locations, and are not easily measured. However, the price of food in the market is easily measured and thus can be used as a proxy for access to food by the poor.

Poverty plays a critical role in reducing the ability of a region to create sufficient demand to ensure the availability of food. Increasing food prices can impact different segments of the population differently. There are the poor who own land and productive assets, those that survive on wage labor, those that have a skill such as hairdressing or clothes making, and those that work in the market (Sen, 1981). Each category of people has different characteristics that may affect how changing food prices impact their welfare. The poor and the very poor may

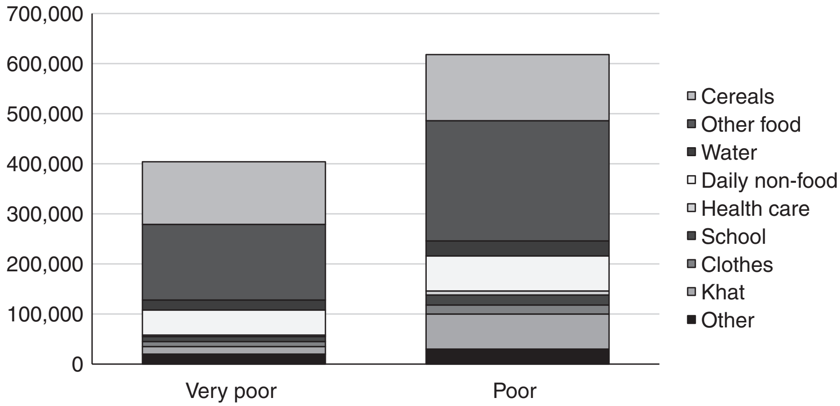


FIGURE 2.3 Expenditures in Somaliland shillings of poor and very poor households in Somalia in a normal year.

Note
The figure shows that very poor households spend 73 percent of their income on food, whereas poor households spend 60 percent of their income on food. When prices increase, the very poor are less able to maintain basic consumption.

have very different household incomes, and thus the impact of food price spikes can vary across these different groups.

An example of the impact of large changes in food prices on human welfare can be taken from Somalia. Figure 2.3 shows an example of the categories of goods that two Somali wealth groups spend in a normal, non-drought year. FEWS NET uses the entitlement approach to group poor people into different categories with variable exposure to changes in food prices, economic shocks and other food security threats. The figure shows that 73 percent of income is spent on food for a very poor family, whereas a poor family spends 60 percent on food. The very poor household is more exposed to abrupt changes in the cost of food relative to income than the poor household, and thus would need gifts or other outside support to ensure that their basic daily food needs are covered during times of shock. If these coping strategies are not available, significant reductions in food consumption is likely to occur (Hillbruner and Egan, 2008; Handa and Mlay, 2006).

Famines and food security crises

When food prices rise dramatically, does a food security crisis result? When does a crisis in food security in a country or region become so severe as to be declared a famine? Does this happen as often as food price spikes? These questions are critical for understanding when the increase in the cost of food is important and how price increases may cause a food security crisis, and when it is not likely to do so.

A famine can be declared only when certain measures of mortality, malnutrition and hunger are met: to have at least 20 percent of households in an area face extreme food shortages with a limited ability to cope; documented acute malnutrition rates to exceed 30 percent; and the death rate be at least two persons per day per 10,000 persons. Famines occur only rarely, there have only been a few in the past three decades (Gráda, 2009). They have complex causes and nearly always occur in regions that have poor governance, have experienced conflict or are otherwise isolated from the international community.

Table 2.1 shows the triggers and the processes that are described in the literature on why famines occur. Climatological triggers, such as drought and floods, are caused by long-term processes of a changing climate or man-made reduction in the productivity of the land, or desertification (Devereux, 2000). Demographic, economic and political triggers and processes have also been seen to be the cause of famines (Shipton, 1990). Each of the theories alone is a partial explanation and will not cause famine by itself. For example, an expanding population that requires an exponential growth in food availability will not cause a famine by itself, since processes of agricultural technology, transformation of transportation networks, technological advancements and industrial processes will also evolve as the population grows to increase food availability to meet the demand.

Like airplane crashes, famines are caused by a sequence or cascade of failures where access, availability and utilization are all disrupted in the same place at the same time. Termed "complex emergencies" by the humanitarian communities, these usually include poor or non-functioning governance, blocked or distorted trade networks, lack of outside assistance, conflict or war disrupted local food production activities, local economic collapse and undermined household coping strategies. A drought alone is not enough to cause a famine, nor is a conflict or high food prices. But when there are multiple triggers and processes occurring at one time, and there is a slow or ineffective response by local government or the international community, then a famine can occur.

In the most recent famine that occurred in Somalia, the causes of the crisis included several years of drought that culminated in a completely failed harvest due to an extreme lack of rainfall, an expansion of the population with a resulting decline in per capita food production and broad failure of entitlements to productive resources, and a severe conflict that prevented

TABLE 2.1 Primary triggers and processes that cause famines

Triggers	*Processes*
Climatological	
Drought	Desertification
Floods	Global Warming
Demography/nutrition	
Epidemics	Malthusianism
Population growth	Demographic shift
Economics	
Market failure	Poverty
Entitlement failure	Infrastructure
Politics	
War	Civil unrest
Response failure	Government policy

Source: derived from Stephen Devereux, Institute of Development Studies, "Summer School on Food Security and Famine Prevention in Developing Countries."

the trade of food and movement of people (Maxwell and Fitzpatrick, 2012). The conflict caused the failure of formal and informal safety nets due to the ongoing lack of governance in the region and the restriction of the activities of international humanitarian organizations due to the activities of the local militant group Al Shabab. The restriction of trade caused very high local food prices, and elevated international food prices further reduced the ability of institutions to import sufficient reserves. Together, these elements caused a famine in Somalia in 2011–12 (FEWS NET, 2012a).

Knowledge of the likelihood that there will be a food security problem is a key way that these crises can be averted. Research conducted during and after famines in Africa in the 1970s and 1980s (von Braun *et al.*, 1998; Watts, 1983) demonstrated that early and focused intervention could break the link between climate extremes and famine (Wisner *et al.*, 2004). This work and others produced after it focused on the social and political context in which environmental extremes, market dysfunctions and lack of governance can cause large-scale food security crises (Corbett, 1988; Cutler, 1984; De Waal, 1988; Khan, 1994; Lele, 1994; Moseley and Logan, 2001).

The links between causes of short-term decline in food production, lack of functioning markets and the consequences for household and community food security led to the development of early warning systems in the late 1980s and 1990s (Mellor and Gavian, 1987; Buchanan-Smith, 2000; Brown, 2008). Together with the advent of large-scale satellite remote sensing and improved computer and communication systems, information about food, food availability and food access has increased dramatically in the past two decades (Davies *et al.*, 1991; Buchanan-Smith, 1994; Hutchinson, 1998). Monitoring and analysis of impending food security problems is a key sector where research on the linkages between weather-related agriculture impacts and food price dynamics can be transformative. Waiting until after a food security crisis has unfolded is not an option if institutions would like to protect social assets.

Over the past three decades, early warning systems have refined their food security indicators to better detect changes in welfare, improved the accuracy of the data they use and increased the timeliness of warnings (Scheel, 2012; Verdin *et al.*, 2005). Early warning systems could be an important vehicle for institutionalizing the interactions between markets and food production, in better understanding supply response to demand and for designing effective policy interventions. Clear connection between the observations and the likely impact of observed shocks on food security situation can be articulated to policy makers by an early warning system, and, if done properly, motivate an appropriate response in local, national and international institutions. The next section, therefore, will focus on describing USAID's early warning system, the data it uses and how it conducts analysis as both a source of information and a target for improved information systems.

USAID's Famine Early Warning Systems Network (FEWS NET)

The early warning organization that the author of this book has worked with and knows most about is FEWS NET. It is just one of many organizations focused on understanding and providing early warnings of food security crises around the world. FEWS NET's objective is to provide early and actionable information for decision makers who can authorize a vigorous and well-funded response to crises when they occur (FEWS NET, 2012b). Because of its role in humanitarian monitoring for the US government, one of the world's largest donors of food aid, FEWS NET has developed a broad and comprehensive set of monitoring tools for all aspects of food security (FAIS, 2012). The datasets developed and maintained by the organization are critical inputs for the research presented in this book. FEWS NET also is uniquely situated to make use of the relationships between environmental dynamics and food prices in food insecure areas to ensure improved outcomes.

FEWS NET has been reporting on food security since the mid-1980s, when the system pioneered the use of satellite remote sensing to monitor droughts and their impacts on food production (Brown, 2008). FEWS NET was designed to provide information on the food security status of communities in semi-arid regions of the West African Sahel and has expanded to work in southern and eastern Africa, Central America and south Asia. It has cultivated a broad cadre of experienced personnel that include social and physical scientists, internationally known experts as well as personnel in each country with experience in the health, agriculture and nutrition fields.

The most visible parts of FEWS NET are its field offices and field representatives in roughly 23 countries, and a contractor office in Washington DC located near USAID that manages and technically directs them. Each office has a country representative and deputy who provide national and sub-national information on the food security status and trends on a monthly basis (Plate 3). A contractor is responsible for employing its country and Washington DC personnel, integrating FEWS NET's global early warning information, resources and training activities, and delivering finished products to information-gathering and decision-making processes of USAID, as well as to a broad range of partners.

FEWS NET works to use the information in monthly food security updates provided by each country office to create clear messages for decision makers at USAID about the situation in a particular region. The organization estimates local food availability, access and utilization with a wide variety of datasets, including remote sensing data, ground measurements of food production measuring the supply of food, and a wide range of other indicators meant to measure food demand in concert with political and economic pressures that may affect a region's food security (Schmidhuber and Tubiello, 2007). Although the early and actionable information that is provided by FEWS NET can result in food security interventions (Davies *et al.*, 1991; Wisner *et al.*, 2004), FEWS NET is not directly involved in humanitarian response, as this is managed by the United Nations' World Food Programme and local, national and international NGOs. Local FEWS NET representatives work to create coalitions through collaborating with groups at the local, regional and international level with common interests, forming alliances that strengthen the combined ability to advocate for the desired outcomes.

Environmental and weather data and forecasts have been embraced by the early warning community, who use it in a risk management framework enabling the incorporation of information about likely impact of growing season climate conditions on food security before the season begins. A fairly low level of certainty is required before further investigation or attention is paid to a region, and enhanced reporting initiated. The humanitarian community, however, requires both quantitative analysis and political pressure before initiating a large-scale humanitarian response. The media and public sentiment feeds into this scenario, with the "driver" of images and stories of human suffering broadcast widely forcing hard decisions that divert resources to an emergency when budgets are tight. A much more systematic, national or regional emergency fund and insurance-based approach would avoid these crisis-based decisions for all involved. Planning ahead and ensuring that resources already in the region can be used flexibly to address urgent needs is possible, but must be put into place before the onset of a crisis.

Conceptual frameworks for early warning

New approaches and methodologies to understanding the causes and consequences of food security have led to a great expansion of the monitoring tools and data collected to provide early warning of food security crises over the past decade. These new approaches have been developed to respond to changes in the global food system, which include information on the global commodity market and regional food trade, energy costs, accelerating urbanization, climate change, changes in food stocks and improvements in the global transmission of information. These factors have possibly led to more food insecurity but the sources of the vulnerability are new and far more complex than the previous, resource-based problems. Poverty, education, disease burden and the market orientation of even isolated, rural farmers continue to be important sources of vulnerability.

The USAID FEWS NET uses the entitlement and livelihoods approach initially articulated by Sen (1981) and further developed by the Overseas Development Institute and others in the humanitarian community specifically for early warning organizations (Scoones, 1996; Boudreau, 1998; Frankenberger, 1992; Maxwell and Frankenberger, 1992). The objective of the livelihoods approach is to evaluate the impact of a hazard on food security outcomes in an operational way. FEWS NET defines livelihoods to be "the means by which households obtain and maintain access to essential resources to ensure their immediate and long-term survival" (FEWS NET website, accessed May 2012). Households obtain access to essential resources through a range of factors including geography, agricultural ecology, ownership of productive assets and inter-household relationships. The geography and agro-ecology of an area determines what people are able to produce or grow while access to productive assets and inter-household relationships dictate the extent to which people are capable of meeting their food and cash needs. The degree to which households are able to maintain access depends on their capacity to withstand and recover from price shocks that hinder regular access to food and income. The objective of the livelihood approach in food security assessment is to estimate sources of income and expenditures for different economic groups in the society, and linking the effect of different shocks on the ability of each community to maintain its entitlements to minimum consumption.

The main advantage of a livelihoods-based early warning system is that it provides a contextualized perspective of food and livelihood security within a region or country. Having a nuanced understanding of the context, or how households operate in normal conditions, analysts can better gauge the impact a shock will have on household food and income access. A livelihoods framework is essential for answering key food security questions such as, how and to what extent have households' normal patterns of food and income access been impacted by an event and are households likely to face food or livelihood deficits as a result? Since humanitarian response is not meant to provide long-term development or to be a social safety net for a country, early warning organizations need to have an understanding of "normal" conditions so that their interventions may return a country to this state (Barrett and Maxwell, 2005).

FEWS NET provides livelihood information for as many countries and regions as possible and has been developing these during the past decade. The core products for the livelihood approach include the following:

- A livelihood zone map divides the country into homogeneous zones within which people share broadly the same pattern of livelihood, including options for obtaining food and income and market opportunities.

- Livelihood zone descriptions accompany the maps. They briefly describe the main characteristics of livelihoods in each zone. On their own, livelihood zone maps and descriptions aid development of monitoring systems by identifying geographically relevant variables to monitor. A total of 36 countries have livelihood zone maps and descriptions that can aid in interpreting the impact of a shock.
- Livelihood profiles provide a brief economic differentiation between groups (wealth groups) and information on the relative importance of different sources of food and income to each. This information provides a basis to begin understanding vulnerability to particular events – i.e., which stresses will impact which populations and how. A total of 18 countries have livelihood profiles on the FEWS NET website.
- Livelihood baselines provide a detailed, quantified breakdown of household livelihood options (food, cash and expenditure patterns) and coping capacity/expandability for different wealth groups in the livelihood zone, highlighting market linkages, and constraints and opportunities for economic growth. They can be used to predict who will be impacted by which shocks, how and to what degree. They can be linked to population information to estimate numbers of beneficiaries and assistance requirements. A total of 11 countries have livelihood baselines.
- Seasonal monitoring calendars combine the seasonal calendars found in the profiles with the information on sources of food and income by wealth group to identify which variables are important to which wealth groups in each zone. This serves as a quick reference tool when developing a monitoring plan. A total of 22 countries have monitoring calendars, although all countries FEWS NET operates in have crop calendars associated with them.

Most countries in FEWS NET's coverage area have zone maps and descriptions and some have baselines, but few have the full complement of products. The products are updated every five years and more frequently in some areas experiencing rapid change. They are the primary way analysis of the impacts of food security impacts of extreme weather or food price shocks are done within the early warning system.

Risk reduction framework for early warning

For the purpose of food security analysis and early warning, the Disaster Risk Reduction (DRR) framework is useful for understanding how household vulnerability to particular hazards relates to risk of food insecurity. The framework provides a practical means for connecting food security conditions to risk instead of waiting for conditions to come to a crisis. Risk can be described as a function of a hazard and the household's vulnerability to the hazard, modified by the household's coping capacity.

The most commonly used definition of the DRR framework is "the conceptual framework of elements considered with the possibilities to minimize vulnerabilities and disaster risks throughout a society, to avoid (prevention) or to limit (mitigation and preparedness) the adverse impacts of hazards, within the broad context of sustainable development" (UNISDR, 2004). Thinking and practice about risk reduction includes a wider and deeper understanding of why disasters happen, a focus on the broader political and economic context, and the necessity of a holistic and integrated approach necessary to reduce their impact on society (Wisner *et al.*, 2004). In the context of early warning of food security crises, it is critical to recognize the multiple causes of food insecurity and reductions in entitlements. Thus understanding livelihoods is central to ability to know where to look for signs of crisis to avert a disaster.

Although much early warning is integrated into risk reduction assessments, the humanitarian community needs very specific information about risk to nutrition outcomes before responding to an emergency, thus the two communities remain rather separate. In the context of this book, risk reduction methods and analysis are a potential area that can enable planning for the potential impact of increases in global food prices on local access. By developing approaches to reduce risk through mechanisms such as grain storage and country-level insurance programs and rainy-day funds, countries can reduce the risk to food security posed by potentially large increases in the cost of food imported from the international market.

Livelihood example: Niger

To show the practical uses of the livelihood approach, and how food prices and climate variability would fit into an understanding of food security outcomes using livelihoods, we need to look at a specific country. The following example from Niger shows the high level of complexity and large number of factors that go into an assessment of the impact of a weather or economic shock on livelihoods in a particular region or zone (Brown *et al.*, 2012). The framework used by FEWS NET is essentially rural, where farmers are reliant on natural resources to make their living and are highly affected by variations in moisture availability. The price of food affects farmers both in the value of the goods they produce as well as the expense of purchasing food on the market when their own stocks are depleted. Integrating non-farming sources of income and environmental shocks in nearby regions into these assessments is difficult due to the ever-widening array of income opportunities and linkages to other regional, national and international economies that even rural economies have. Information on food prices is thus critical for these assessments as African economies work to cope with increasing climate variability and population growth (Funk and Brown, 2009).

As of this writing, Niger has a population of approximately 16 million people, with approximately 14 million in rural areas (CIA, 2012). The rural population includes crop farmers and herders, and the degree to which they rely on the one or the other activity is highly determined by the amount of annual rainfall received in the region, and the interannual rainfall variability, which increases the farther north one goes. This vulnerability to weather fluctuations fundamentally shapes the understanding of local livelihoods that FEWS NET uses to monitor food security in the area, although other considerations also affect that understanding, including soil conditions, proximity to main market centers, cross-border trade and special local resources such as salt deposits that can bring market income.

Rainfall varies from north to south of the country, ranging from 50 mm or less in northern desert areas to around 800 mm at the southern-most tip of the country. Rainfall dictates the limits of pastures before true desert takes over (the zone of pastoralism), as well as the limits of crop cultivation before pastures take over (the agropastoral zone). It also determines the main rainfed cultivation zone and the relative emphasis on different types of crops (notably the balance between millet and sorghum) (Plate 4). Access to groundwater is also a critical factor in eight of the 13 livelihood zones, as it permits irrigation for either crop development or for insuring farmers against in-season rainfall irregularities (FEWS NET, 2011c).

The calendar shown in Figure 2.4 shows that livelihoods in Niger are dominated by a single rainy season on which the great majority of people in Niger depend for both crop cultivation and pasture renewal. The abundance of rainfall during the four months from June to September dictate the success of the agricultural year, with the start of the season beginning later as one moves further north. Dependence on a single harvest is inherently risky, since there is no second season to alleviate crop failure if the rains are not adequate. For poorer people it also means that each year there is a progression from easier food availability just after the harvest to a lean season just before the next harvest when household stocks are long gone and money for food is very tight. The lean season is also when local food prices are the highest, with strong seasonal variability from pre- to post-harvest (Brown *et al.*, 2009). This season is made the harder because it is a time of peak physical agricultural activity and also of outbreaks of malaria and meningitis, which inhibits work and increases the risk of acute malnutrition (FEWS NET, 2011c).

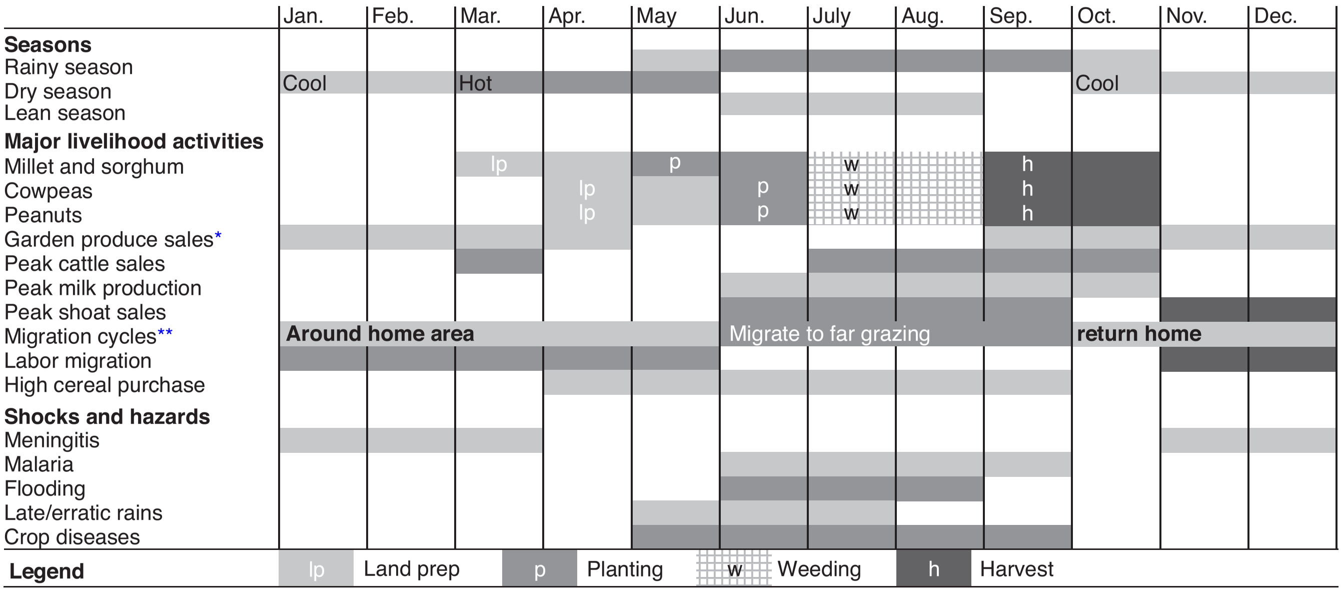
For monitoring potential food insecurity, climate variables can impact production, particularly sowing and germination dates in June and July. Farmers' decisions involve something of a gamble against an erratic start to the season with risk of drying up germinated seed and resulting in extensive re-sowing, sometimes too late for a successful crop, or abandonment of fields for the season (Brown and de Beurs, 2008). Another particularly delicate moment where growing conditions can have large impacts on ultimate production is the flowering stage for cereals in late August/September leading to the formation of the grain. If there is a two-week or longer break in showers during this period, significant reductions in yields could impact production over wide areas.

For livestock, low levels of green vegetation during peak growing periods could cause a pasture crisis. The failure of herds to return to home from far away grazing areas and very early migration out of the home area before the rains are indications that local pasture conditions are too poor to sustain herds (FEWS NET, 2011c). These conditions can be monitored remotely using satellite data, but must be put together with information gathered in the country itself.

Across Niger, many people migrate during the dry season when there is little agricultural activity to try to find paid work in main towns or in neighboring countries, notably Nigeria, Côte d'Ivoire, Burkina Faso and Libya. In bad years, a greater number of people tend to go on work migration, and this may begin well before the harvest. Migration rates are an important indication of anticipated harvest failure and the pressing need to maximize other income during the year (FEWS NET, 2011c).

Market signals and the cost of food in local markets are of critical importance for effective early warning of food security problems in Niger. An early rise to food prices after the harvest in the late fall is an indication of a poor harvest, since poor people may already be buying staple foods (Figure 2.4). Another signal is the failure of local cereals prices to fall significantly in the immediate post-harvest period. As the year progresses, another crucial signal is the extent to which staple grain prices rise before the next harvest. Given the heavy dependence of poorer people on the grain market even in normal times, early and steep staples price rises will indicate both a particularly harsh lean season as well as probably very early beginning to it.

Variations in the prices and availability of livestock in the markets are also important. There can be unusual trends in the numbers of animals offered for sale that indicate poor pasture conditions and an impending crisis in pastoral communities. Very few animals may be



* Garden produce includes irrigated vegetable sales that extend far into the dry season.

** These livestock migration cycles refer to the general pattern for animals – notably cattle – that are taken on seasonal grazing migration from the home areas by transhumant herders, agropastoralist and sometimes also farmers.

FIGURE 2.4 National seasonal monitoring calendar for Niger (source: from FEWS NET Niger livelihood zoning document, 2011).

Note

FEWS NET provides a seasonal calendar showing each of these elements for each livelihood zone in each country.

offered for sale after the rains because herds have not returned to their home from far-away pastures. Observers may see a glut of animals and very low prices in the later dry season, as people try to sell off animals because they cannot find pasture or afford fodder for them, or because they desperately need the money for food. Livestock prices can fall to extremely low levels. A crucial part of market surveillance is therefore the trend in terms-of-trade of livestock for grain.

Seasonal variability in grain prices contributes to the insecurity of highly vulnerable pastoral communities during times of poor rains, where they are forced to sell their animals when food prices are their highest due to lack of pasture (Figure 2.5) (Brown *et al.*, 2008). FEWS NET focuses on livestock prices because they represent savings, enabling access to food when times are poor. When a poor farmer sells his last goat to buy an amount of grain that would not last the family for ten days (less than 50 kg), then a food security crisis is imminent. Early warning needs to pick up on these trends well before this moment (FEWS NET, 2011c).

Data for food security analysis

The example given above shows how detailed and specific information has to be for useful and actionable food security assessment. The data and analysis that form the basis for

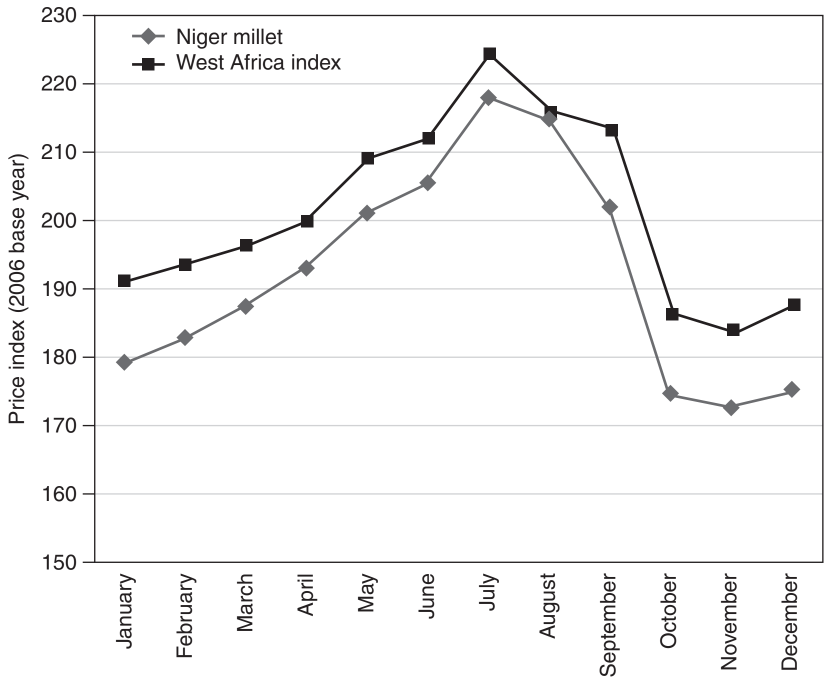


FIGURE 2.5 Average monthly price in CFA per kilogram of millet (benchmarked to the year 2006) in Niger from 2002 to 2012, from 13 markets, plotted with the West Africa price index (source: data from FEWS NET, analysis derived from Brown *et al.*, 2010 and 2012).

Note
The figure shows the increase in prices in the pre-harvest season of July and August, followed by a decline during the harvest during October and November in this semi-arid region.

understanding the nature and severity of a food security problem is diverse, and includes information on food prices, environmental conditions, trade flows and other information. Remote sensing plays a key role in food security assessment, as it can be an early indicator that there may be a food production problem, and is usually the least controversial, providing a focus point for negotiations and discussions among the many parties who must come to an agreement before a response can occur (Brown *et al.*, 2007). The datasets that are available for monitoring food production have expanded from information on vegetation health in the 1980s to accurate rainfall estimates (Xie *et al.*, 2002), yield impact models (Vermeulen *et al.*, 2012), high resolution cropped area estimations (Husak *et al.*, 2008) and others that enable the continuous and multi-faceted monitoring of the growing season in every region today (Maselli *et al.*, 2000; Bolton and Friedl, 2013).

The development of remote sensing systems to monitor environmental conditions provided for the first time a way to monitor current climate variations over an entire continent for very little expense (Tucker, 1979). Before the advent of remote sensing systems, information on growing conditions was difficult to get and extremely localized, with large areas away from cities and roads left unmonitored. Remote sensing information can be used to identify widespread weather-related food production deficits. Early efforts of famine warning found that estimating the impact of climatic hazards is more challenging than simply analyzing the necessary physical evidence of an ongoing drought or the severity of a flood. There is large variation in the amount of climatic stress that vulnerable groups can endure before real and widespread destruction of livelihoods occur (Dilley, 2000). Although the physical characteristics of crop yield reductions due to rainfall deficits can be specified, determining the impact of this reduction on food security in the place and time that it occurs is dependent on the context. For example, a 50 percent reduction in millet production due to erratic rainfall that occurs after several years of good harvests is far less likely to result in sufficient food insecurity to warrant intervention than the same reduction after several years of below-average production.

The example given for Niger livelihood analysis above shows the wide variety of data that a food security assessment requires. In Table 2.2, the social and economic data that are used for food security assessment is presented. Table 2.3 presents the remote sensing and biophysical products regularly used for assessment of food production variability. Neither table presents an exhaustive list of the products used by early warning organizations (see Brown, 2008, Table 3.1 for a more comprehensive list) but seeks to present the data that are available and are actually used for food security analysis through the efforts of early warning and other monitoring organizations.

Communication of information about food security status occurs through a system of reports that are written each month in a FEWS NET country office by the country representative and then sent to a central office in Washington DC for posting on an internet database (www.fews.net). These reports provide critical information upon which USAID makes decisions about where to send assistance and in what form. To identify the onset of food security crises, FEWS NET analysts use a "convergence of evidence" approach to combine biophysical and climate information with local and regional socio-economic household livelihood analysis. Specifically, in-country analysts construct an assessment of food availability using production statistics as well as rainfall, temperature and vegetation data derived from local measurements and from remote sensing to identify abnormally wet and dry periods (Brown, 2008). The analysts also evaluate market conditions, threats to pastoral resources,

TABLE 2.2 Socio-economic data available for food security monitoring

Data type	*Product*	*Description*	*Spatial extent*	*Resolution*	*Time step/temporal extent*
Food prices	FEWS NET price database	Retail prices, locally relevant commodities	35 countries	At least 3 markets in each country	Monthly, starting in 2003
Food prices	FAO Global Information and Early Warning System (GIEWS) global price database	Wholesale prices, mostly cereals, ingests and distributes FEWS NET data	75 countries	Mostly capital cities	Monthly, variable start dates, earliest 2000
Food prices	Historical price data from previous USAID data gathering systems	Extensive databases of all commodities	15 countries	Hundreds of markets in each country	Daily, 10-day and monthly, ending in 2000
Food prices	Country-level price information systems	In-country datasets collected by national governments, including livestock, goods, services and food prices	Nearly all, not openly shared in most cases	Most cities and regional capitals	Daily and monthly, varies
Employment	Labor markets	Informal monitoring by country representatives	FEWS NET presence countries only	–	–
Population	Population density maps, updated to capture migration or large population movements	Population explorer, based on LandScan data	Global	1,000 m	Continuously updated, most recent population data, emergency information
Trade flow maps	Flow maps providing information on market sheds and movement of goods across regions	Trade flow information derived from experience and knowledge of market networks significant to food security	Information on trade flows from local governments, market information systems, UN agencies, network partners, market actors	One map per country for grains important for local food security, livestock, labor	Updated every 5 years or less, depending on area and rate of change
Amount of cross-border trade	Cross-border trade reports	Survey results and analysis	88 commodities and livestock in 26 cross-border markets in East Africa	–	Monthly

Source: derived from Brown, 2008, updated and summarized.

availability of wild food and, ultimately, the agricultural economy as a whole to understand what impact these growing conditions may have on overall food security. Contextual livelihood information is then used to understand how these market and environmental conditions will impact specific groups in each community in the country (Verdin *et al.*, 2005).

Effectiveness of early warning systems

Research conducted during and after famines in Africa in the 1970s and 1980s (von Braun *et al.*, 1998) demonstrated that early and focused intervention could break the link between climate extremes and famine (Wisner *et al.*, 2004). With the enormous expansion in communication systems during the past decade, warning has moved from being focused on the past few months and the current situation, to warning of developments that will occur in the next six months. This "earlier" early warning provides timely, quantitative and comparable information about the food security situation across multiple continents.

Unfortunately, early warning did not result in an early response during the food security crisis that occurred in the Horn of Africa in 2011. According to a joint report by Save the Children and Oxfam Great Britain published in 2012, there was accurate and quantitative early warning of the food crisis over a year before an adequate response was made. The report states

> across Ethiopia, Kenya, Djibouti and Somalia this crisis has played out very differently, but common to all of them was a slow response to early warnings. Early signs of an oncoming food crisis were clear many months before the emergency reached its peak. Yet it was not until the situation had reached crisis point that the international system started to respond at scale.
>
> *(Hillier and Dempsey, 2012)*

Although early warning systems have greatly increased their responsiveness and ability to detect and analyze information to provide earlier warnings, there has not been a concurrent change in the humanitarian systems to respond to these warnings. Neither longer-term development programs nor shorter-term subsistence support from the humanitarian community has changed in order to take the guidance of the early warning community as seriously as they should.

The Hillier and Dempsey (2012) report focuses on the need for a re-examination of the commitment to providing needed entitlement transfers during times of crisis to save lives and the livelihoods of those afflicted. In order to raise large sums for humanitarian response, adequate media and public attention is required to motivate the movement of funds (Maxwell and Fitzpatrick, 2012). This misses the point of early warning – if analysis and documentation show that there is a high probability of an event happening, response needs to begin immediately before the media and political reaction begin. At the moment, response does not occur until after the situation reaches a crisis point and images of starving children, migrating families and parched fields hit the media. This perpetuates chronic vulnerability to recurrent drought and dependency on humanitarian assistance in places like East Africa.

The report points out that there is a huge number of organizations and institutions working on food security in East Africa. Not only are the national governments themselves highly focused on food security issues, but there are many national, international and United Nations-affiliated organizations that analyze information, provide support and conduct short- and

TABLE 2.3 Biophysical data for monitoring food production variability

Data type	*Product*	*Description*	*Spatial extent*	*Resolution*	*Time step/temporal extent*
Precipitation	NOAA[1] Rainfall Estimate	Multi-sensor (Meteosat, TRMM,[2] AMSR/E[3]) and gauge merged model	Regional (Africa, South Asia)	0.1 degree	Daily, 10-day 2006 to present
Precipitation	CHiRP[4] data	Geostationary IR[5] temperature (Meteosat/AVHRR[6]) and gauge merged model	Global	0.05 degree	Daily, 10-day 1980 to present
Precipitation	TRMM[2] – Tropical Rainfall Monitoring Mission	Multi-sensor and gauge merged model	Global	0.25 degree	Daily, 1997 to present
Precipitation	Global Telecommunication System Station Data	Station data, daily, automatically delivered to WHO[7] networks	Global	Point	Daily historical series vary
Precipitation	Rain gauge networks	Country-level station data, variable densities, available only in each country, not openly shared	Nearly all countries	Point	Daily
Season descriptors	Start of season, end of season, length	Determines beginning of growing season, based on rainfall data	Regional (Africa, Central America, Haiti)	0.1 degree	Every 10 days, no historical time series
Lake levels	Global reservoir and lake monitor	Satellite altimetry and observations	Global	Point	Daily, when observations permit
Yield models	Water requirement satisfaction index (WRSI) crop model	Estimates potential percent reduction in crop yields by crop type	Regional (Africa, southwest Asia, Central America, Haiti)	0.1 degree	Daily, no historical time series
Pasture conditions	Rangeland WRSI	Estimates rangeland grass condition	Regional (Africa)	0.1 degree	Daily, no historical time series
Rainfall and temperature forecast	NOAA Global Forecast System	Estimates precipitation 1 to 7 days into the future	Global	0.25 degree	Daily
Snow depth	Northern Hemisphere snow depth from data assimilation using Community Land Model	Model that estimates snow depth in centimeters	North of the equator	0.5 degree	Daily, limited time series

Evapotranspiration (ET)	ET monthly anomaly product	MODIS Land Surface Temperature-based estimate of irrigation water	Regional (Central Asia)	1 km	Monthly, 2000 to present
Temperature	MODIS Land Surface Temperature	Estimates temperature of land surface	Global	1 km	Daily, 2000 to present
Vegetation	Normalized Difference Vegetation Index (NDVI)	Advanced very high resolution radiometer (AVHRR)	Global	8,000 m	Daily, 1981 to present
Vegetation	eMODIS NDVI	Moderate resolution spectroradiometer (MODIS data)	Global	250 m, 5,000 m	Daily, 2000 to present
Vegetation	SPOT[8] NDVI	SPOT vegetation data	Global	1,000 m	Daily, 1998 to present
Vegetation	NDVI, surface reflectance	Landsat	Global, not complete coverage, less in cloudy regions	30 m	Variable, repeat overpass time every 16 days, available 1960s to present
Land cover	Multiple sensors, multiple products	Agriculture land cover, fields and farms, natural vegetation types	Global, not validated in many places	30 m to 8,000 m	Annual, periodic, varies
Agricultural fields (cropped area)	High resolution imagery	Ikonos, Quickbird, Rapid Eye, GeoEye	Global, not complete coverage, less in cloudy regions	1 m to 20 m	Varies, record starts approximately in 2000

Source: derived from Brown, 2008, updated and summarized.

Acronyms

1 National Oceanic and Atmospheric Administration (NOAA).
2 Tropical Rainfall Monitoring Mission (TRMM).
3 Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E).
4 Climate Hazard group InfraRed Precipitation with Station (CHIRPS) data.
5 InfraRed (IR).
6 Advanced Very High Resolution Radiometer (AVHRR).
7 World Health Organization (WHO).
8 Satellite pour l'observation de la terre vegetation (spot vegetation).
9 Normalized difference vegetation index (NDVI).

long-term programs focused on improving the food security situation. All these organizations saw the crisis coming, had conferences and meetings, and tried to set alarm bells ringing in early 2011 (FEWS NET, 2011a).

In 2011, areas of Ethiopia and Kenya and most of Somalia were already experiencing extreme levels of food insecurity due to drought in previous years and deteriorating purchasing power due to high food prices. Seasonal climate forecasts, when examined by a multi-agency climate outlook process, showed high probabilities of below-average rainfall (Nyenzi *et al.*, 2000). The region was very dry after very poor rainfall in 2010 – the driest in 30 years in the eastern Horn (Maxwell and Fitzpatrick, 2012; FEWS NET, 2011b). Thus there was clear and consistent information about the severe and worsening food security conditions in the Horn starting in early 2011. The humanitarian community clearly stated that although they were aware of the issues, they could not get a decision to act "up the chain of command." Clear decision making was required to mobilize the scale of resources needed to respond adequately to avert the crisis. Ultimately, it was only when over ten million people were at risk and the crisis was declared a "famine" that funds were appropriated to provide adequate resources to intervene (Lautze *et al.*, 2012). This is clearly a failure of early warning, but not because of the timeliness or content of warning, but because of the inability of the community to respond appropriately.

The lessons for the humanitarian community from the 2011 crisis include a focus on managing the risks, not the crisis. Humanitarian organizations cannot wait for certainty before acting, and should develop a common approach for response to quantitative triggers that will result in actions. As indicators of food security crises improve, the obvious lag by countries and institutions to these indicators becomes more apparent (Lautze *et al.*, 2012). Earlier response to droughts in vulnerable regions is necessary to avoid long-term damage to the economy and to livelihoods. Integrating the impact of climate variability into food price and food security analysis should clarify the likely impacts of droughts on outcomes. These lessons can be implemented through:

- National governments should recognize their primary responsibility to meet food security needs through transfers and programs, and provide political leadership for drought response.
- The international aid community should embed a risk reduction approach into its work, allowing long-term development interventions to adapt to changing environmental context.
- All organizations should undertake preventative humanitarian work in response to weather and climate forecasts instead of waiting for the growing season to be over before responding to the situation.
- Donors should provide more agile and flexible funding mechanisms to build recurring-crisis response into development programming to enable funds to be released more quickly and to support pre-emptive or early response that is effective before the crisis becomes fully apparent (Hillier and Dempsey, 2012).

Given these challenges to effective early warning of crisis, it is not very likely that the improved understandings provided in this book regarding the connection between food production and food prices will result in a reduction in the loss of life during a large crisis. A real transformation of the way crisis response is funded and the structure of the humanitarian community must be made for that to occur. Despite this, a better understanding of how extreme climate variability lead to local and regional changes in food prices, and how this may affect food security of these areas is important to achieve. Improving our knowledge of emerging and ongoing food security crises with regular reporting and integration within the humanitarian communities remains important.

Summary

This chapter introduced and defined elements of food security, and how they are currently used in early warning and response to crises within an early warning system. Famines still occur today, and are caused by complex emergencies that include both issues of the availability of food and the ability of households to purchase it. Food access is central to food security assessment, but using prices and market information within early warning and humanitarian systems has only recently been developed. Remote sensing information is relied upon to understand variations in food production, and the information used to assess food availability in a region. An example of livelihoods from Niger shows the level of complexity that is currently used to assess food security. The conceptual frameworks highlighted in the example are mostly rural and agricultural, and are problematic when urban food security is considered.

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3

CLIMATE VARIABILITY, AGRICULTURE AND REMOTE SENSING

Chapter objectives

This chapter describes climate variability and how it can be measured using remote sensing information. It defines climate variability, describes global trends in the temperature record over the past 50 years and describes how these trends are likely to impact temperature. Remote sensing of vegetation is presented as an alternative to precipitation datasets, to ensure comparability and reliability in regions with few weather stations. Analysis of the growing season is presented using vegetation data, and an example of how models assessing variations in growing conditions can be used to estimate national-level food production is presented. Finally, an assessment of the impact of development and agricultural investment on vulnerability to climate variability is used to remind the reader of the effect of resources on outcome.

Climate, climate variability and climate change

Climate is the average weather over many decades in any one location. Climate variability and change are often used interchangeably, but here they have distinctly different meanings. Climate change refers to any statistically significant and persisting change in the mean state of the climate over a long period of time (typically 30 years or longer). The Intergovernmental Panel on Climate Change (IPCC) has defined climate change being change attributable to human activity. Climate variability refers to the variations in the mean state and other variations on temporal and spatial scale beyond those of individual weather events. Variability may result from natural internal processes within the climate system (internal variability) or from variations in natural or anthropogenic external forces (external variability) (IPCC, 2007b). In this book, I have chosen to focus on climate variability, since the time period over which climate change occurs is too long to be easily integrated with the rapid change in household vulnerability and the economic context in which food security crises occur. Understanding the impact of climate and climate variability on food availability and food access over a period of the last decade and the next will require highly accurate observations of weather and climate, and an understanding of economic and social context in which these shocks occur (NAS, 2004).

Climate variability can bring extremes in weather that lead to droughts, floods and other natural weather events. These extremes can be exacerbated by the underlying trends in the climate. Variability is caused by planetary-scale trends and cycles in the earth's land, ocean, atmosphere and life processes. Some of these cycles are multi-year events such as the El Nino Southern Oscillation or ENSO, the north Atlantic oscillation, and other cycles that result from longer-term ocean circulation (Chen *et al.*, 2004). Climate cycles can cause several months of unusually wet or dry weather in a community. These extreme events can have a profound influence on agricultural production and livelihoods of people who rely on natural resources for their living (Chimeli *et al.*, 2002). When these cycles occur in places already experiencing trends in rainfall due to climate change, it can result in economically significant shifts in species if dry or wet conditions due to climate cycles interact with longer-term trends, resulting in long periods of extreme conditions (Gutschick and Bassirirad, 2003; Tschirley and Weber, 1994; Katz and Brown, 1992).

Global environmental change is a concept that connects large-scale changes in human society with natural and anthropogenic changes in natural systems. The International Geosphere-Biosphere Programme (IGBP) was established in 1987 to coordinate international research on global- and regional-scale interactions between human systems and the earth's biological, chemical and physical processes (IGBP, 2012). As Steffen *et al.* (2012) state in the executive summary of their book:

> Begun centuries ago, this transformation has undergone a profound acceleration during the second half of the 20th century. During the last 100 years human population soared from little more than one to six billion and economic activity increased nearly 10-fold between 1950 and 2000. The world's population is more tightly connected than ever before via globalization of economies and information flows. Half of earth's land surface has been domesticated for direct human use.

These changes are likely to have a profound impact on agriculture, as humanity erodes the soil, pollutes the water and changes the ecological systems on which agriculture is based (Steffen *et al.*, 2012).

Measuring climate variability that is relevant to agriculture is challenging. Determining how likely it is a single farm will experience drought in a particular year may require three decades of high quality meteorological data as well as a comprehensive understanding of the amount of moisture the crop being planted requires for optimal growth (Zell *et al.*, 2012). Climate data records, or a time series of measurements of sufficient length, consistency and continuity to determine climate variability and change, are needed in order to determine how a location is changing (NAS, 2004). Even with adequate meteorological data, understanding the amount of moisture required for a particular crop necessitates measurement of the soil composition, humus and organic content of the soil, rooting depth of the crop and the specific genetic makeup of the plant variety (Deryng *et al.*, 2011; Wit and Diepen, 2007; Rojas, 2007; Hansen and Indeje, 2004). Underlying trends in soil characterstics due to a lack of replenishment of nutrients, in the characteristics of the crop being planted or in the climate variability itself will reduce our ability to estimate the impact of climate variability on food production.

As the global population and economy has expanded, agriculture has moved into areas where climate variability has more impact. This expansion, coupled with improvements in technology, has enabled humanity to produce enough food for all. Although there are droughts and other extreme climate events in any one year, the sheer scale and diversity of the agriculture system has protected global production from these variations. Local communities, however, can be profoundly affected by these short-term events, and if their vulnerability to changes in production is high, then even brief climate perturbations can have a long-term impact (Simelton *et al.*, 2012; Bindraban and Rabbinge, 2012; Ericksen *et al.*, 2011). The drivers of change and vulnerability to climate include technology transformation, expansion of population and dietary preferences. Table 3.1 describes the proximate drivers of global environmental change that show the connection between human activities and the resulting environmental impact.

Agriculture is a major contributor to environmental change, as it drives land use, atmospheric pollutants of methane and nitrogen oxides, water pollution, biodiversity loss and other effects (Lashof *et al.*, 1997). Global societal transformation has multiple, cascading effects on natural systems at a variety of scales (Shindell *et al.*, 2012; Reid *et al.*, 2005). Steffen *et al.* (2012) provide a broad overview of these changes and their interaction with social systems for interested readers. Our focus in this book is on agriculturally relevant climate variability that has been measured with the satellite remote sensing data record over the past three decades, and how these changes impact agriculture and ultimately food availability. Satellite data represents an enormous improvement in our knowledge of weather and climate globally, but there is still much that we need to know that we are still unable to measure. These include the impact of farmer management, the yield potential of the crop being grown, the impact of stress on plant activity and performance throughout the growing season, and geographically and time specific information on what crops are being grown where. These gaps in knowledge revolve around being able to identify and quantify trends through time in order to understand changes that are affecting society.

The extreme drought seen in Texas in 2011 is an excellent example of these questions. The American southwest experienced the worst drought in 45 years, with high temperatures and very low rainfall, starting in January 2011. The drought, which spread from Arizona to Florida, hit central and northern Texas the hardest, with virtually no rain and significantly above average temperatures for the first six months of the year. Was this drought part of a broader drying trend that is likely to re-occur, or was it a one-time anomaly that won't be repeated within our lifetime? This question is central to the policy and technical response to the event, because some short-term responses to the drought can actually increase vulnerability if the drought is one of many instead of being a rare event. This is particularly true for food security and humanitarian response. Emergency food aid can be destructive both of local agricultural economies as well as to longer-term strategies to reduce vulnerability, e.g., out-migration, income diversification and adoption of new technologies in agriculture (Barrett and Maxwell, 2005). On the other hand, if no response occurs to a crisis, large-scale degradation of social and economic capital may occur. Thus the question of stability of a climate record and its ability to capture both the current state as well as long-term trends is central to the discussion of remote sensing information in this chapter.

Agriculturally relevant climate trends

Although most rainfed agricultural crops are sensitive to variations in temperature and precipitation, and suffer yield losses during extreme weather such as high winds, tropical storms and fire,

TABLE 3.1 Proximate and underlying drivers of global environmental change

Environmental change	*Proximate driver*	*Underlying driver*
Land	Forest clearing (cutting and burning)	Demand for food
	Agricultural conversion (tillage, for row crops, terracing, tree, crops)	Dietary preferences
	Land abandonment	Recreation
	Urban/suburban expansion	Demand for goods and services (technology, cars, etc.)
	Mining	Cultural change
		Urbanization
Atmosphere	Fossil fuel burning	Demand for mobility
	Agricultural practices (nitrogen,, methane)	Demand for consumer products
	Biomass burning	Demand for food
	Industrial technology	Technology change
Water	Dams, impoundments	Demand for water (direct human use)
	Municipal water systems and leakage/evaporative loss	Demand for food (irrigation)
	Transportation systems	Demand for consumer products (industrial processes)
	Waste disposal techniques	Lack of investment in systems (waste)
	Industrial water use/technology, change (i.e. natural gas fracking)	Demand for mobility
	Agricultural irrigation	
Coastal/marine	Sediment and nutrient pollution, from land cover conversion	Demand for recreation
	Groundwater removal	Demand for food/dietary preferences
	Fishing intensity and techniques	Landscape amenity
	Sewage treatment technology	Lifestyle/cultural preferences
	Urbanization/coastal development	
	Pollution from industry, consumers, chemical spills	
Biodiversity	Clearing of natural/forest ecosystems	Demand for food
	Invasive species	Landscape amenity
	Expansion of urban areas/suburbs	Lifestyle

Source: derived from Table 1, Executive Summary of Steffen *et al.*, 2012.

Note
Proximate drivers are the immediate human activities that drive a particular environment change. Underlying drivers are related to the fundamental needs and economic desires of individuals or groups.

it is much less clear how these events will affect food availability across large areas or how vulnerable different communities are to these impacts. In the next two decades, the demand for food is estimated to double, necessitating significant investments in increased food production (IAASTD, 2008). This increased demand will heighten the negative impacts of reductions in food production due to the weather, particularly if they occur across large areas during the same season, affecting the same crop. The competition for highly productive agricultural land will increase as the demand for energy and food increases (Harvey and Pilgrim, 2010). How these agricultural investments will be made, and whether they increase or decrease society's vulnerability to food insecurity will depend what the system's responses are to stress from a variety of sources.

Research during the past decade has documented changes in climate and land-atmospheric response that may affect agriculture (IPCC, 2007b). These include increasing temperatures, changing precipitation regimes and shifting seasonal cycles. Tropical agricultural systems are particularly sensitive to changes in evapotranspiration and movement of the monsoon (Zhao and Running, 2010). What are the changes in temperature and precipitation that have been observed over the past three decades? One of the most certain and clearly documented changes is the global average temperature, which has risen significantly over the past century. Figure 3.1 shows the global temperature anomaly from 1850 to the present day, with coverage of the land surface improving over time. The figure is based primarily on direct thermometer readings and has approximately global coverage. There has been a general warming in the mean global temperature since the beginning of the industrial revolution, with much more significant warming in the northern latitudes than in the tropics.

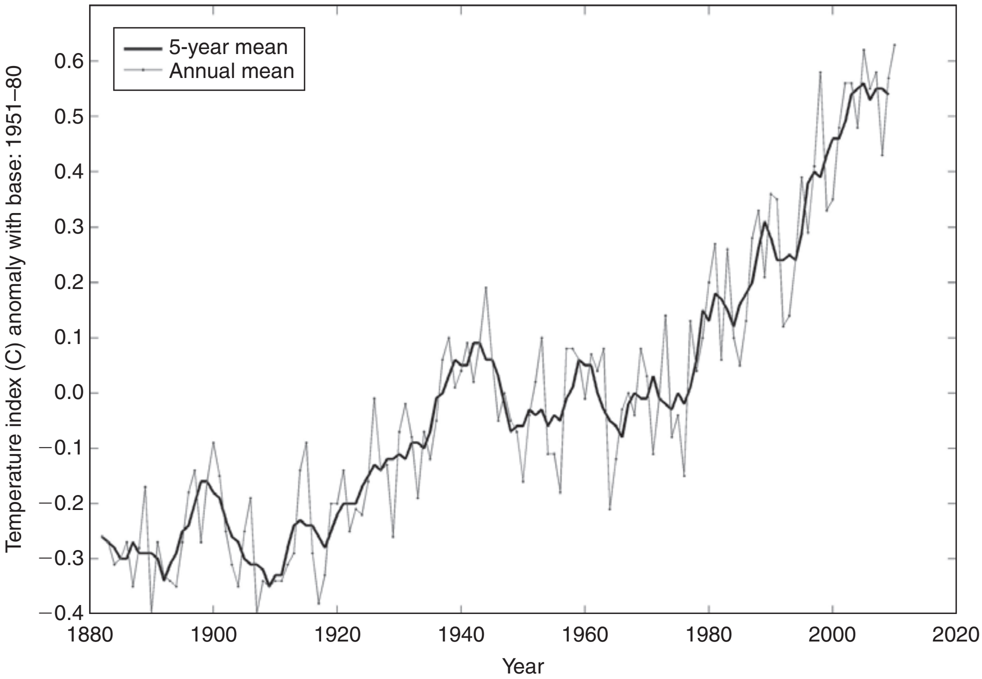

FIGURE 3.1 Global temperature index anomaly with base years 1951–80, showing large increases in global temperature over the past century (source: data from Hansen *et al.*, 2006).

Temperature changes are much easier to measure than changes in precipitation, due to the mixing of the atmosphere and the relative ease of making accurate temperature measurements (Plate 5). Regarding the impact of observed warming on precipitation, in 2007 the fifth Intergovernmental Panel on Climate Change (IPCC, 2007a) assessment stated:

> the increased atmospheric moisture content associated with warming might be expected to lead to increased global mean precipitation. Global annual land mean precipitation showed a small, but uncertain upward trend over the 20th century of approximately 1.1 mm per decade. However, the record is characterized by large inter-decadal variability, and global annual land mean precipitation shows a non-significant decrease since 1950.

To estimate changes in precipitation globally, one of the best datasets to use is the Global Precipitation Climatology Project (GPCP) precipitation merged dataset for 1979–2010, version 2.2, which combines precipitation estimates from multiple satellite observations acquired from Special Sensor Microwave Imager emission and scattering algorithms, GOES Precipitation Index, Outgoing Longwave Precipitation Index, rain gauges and TIROS Operational Vertical Sounders on NOAA polar orbiting satellites (Adler *et al.*, 2003) (Plate 6). Merged satellite and gauge datasets such as the GPCP have distinct advantages over gauge data alone, as they provide information in places and times when ground data are not available, and have a greater chance of observing a rainfall event due to their use of data from multiple sensors and observations.

Deriving trends and extreme rainfall events from any global precipitation dataset remains difficult, however, due to the lack of adequate ground observations over much of the developing world and the high temporal and spatial variability of rainfall (Dinku *et al.*, 2008). Plate 7 shows the anomaly of the GPCP for 2010 from the 1988 to 2004 base period. The image has white for non-significant trends and colors for where the trends are significant. What the reader will notice is how few places have rainfall trends, and how most trends are in the ocean. The analysis does not do well in capturing trends that are societally relevant, for example changes to the start of the growing season in tropical countries, or changes in rainfall intensity causing more floods. Documenting these more meaningful rainfall trends requires extremely careful analysis, lots of very high quality data and a great deal of specific knowledge of local vulnerabilities, hazards and livelihood strategies.

Rainfall variability

New assessments using proxy datasets such as those derived from the Gravity Recovery and Climate Experiment show balances in groundwater and global runoff into the oceans have trends that are quantifiable and significant for local agricultural conditions (Rodell *et al.*, 2009; Gosling and Arnell, 2011; Syed *et al.*, 2010). By merging models with observations, different disciplines are beginning to demonstrate increasing precipitation intensity and large-scale changes in drought and flood event occurrence. A recent assessment of ocean salinity observations from 1950–2000 shows that the global water cycle is indeed intensifying at a rate of 8 percent per degree of surface warming (Durack *et al.*, 2012), likely leading to increased droughts and intense rainfall events over land even if we cannot yet observe these changes. We can expect increasing weather impacts for agriculture as the climate changes (Ohring and Gruber, 2001; Turvey, 2001).

Precipitation has very large spatial and temporal variability, and therefore is very difficult to model. Rainfall measurements need to be very accurate over a wide range of spatial and temporal variability (Zeng, 1999). Capturing this day-to-day and year-to-year variability of rainfall is very difficult in a model. Rain gauge observations are often biased due to the effect of wind and other factors (Sevruk, 1982), but in most areas this bias is relatively small compared with satellite precipitation estimates based on cloud identification or rain rates that either systematically overestimate or underestimate the amount of actual rain falling (Xie and Arkin, 1995). Gauge data are the basis for all methods to estimate precipitation, and therefore the frequency of observation, density of the network and accuracy of each measurement is critical for the quality of the rainfall models, regardless of the other inputs. Rain gauge data are not available over most oceanic regions and sparsely populated regions. Averaging point values on a sparse, irregular grid into surface means introduces sampling errors that can be significant and non-random. Places with high variability of rainfall and low sampling with gauges will have systematically incorrect rainfall estimates (Nicholson, 1986; Grist and Nicholson, 2001).

Agriculturally relevant drought conditions both regionally and globally are much more clearly assessed than long-term trends because most droughts are measured over a period of months, a relatively short period of time that is well suited to satellite rainfall data records. New online tools such as the Global Drought Monitor are now available to provide timely and quantitative information about regions experiencing drought. Drought is defined as an extended period of time when a region notes a deficiency in its water supply, whether surface or groundwater. This generally occurs when there is consistently below average precipitation. Because drought is often defined in terms of ecosystems and economic damages, a global drought map is difficult to interpret and determine if it is significant for food security or food production in a particular area. Nevertheless, these products will help the food security community to better understand rainfall variability and its change over time (Bolten *et al.*, 2010; Rojas *et al.*, 2011).

Despite the technical difficulty of creating global precipitation datasets, satellite-derived rainfall datasets have greatly improved in recent years and form the basis for much knowledge of drought and drought impacts (Huffman *et al.*, 1995). They do have some drawbacks, however, for early warning of food security crises, since the accuracy of the products depend directly on the density and fidelity of ground observation networks. Countries such as Kenya, for example, have hundreds of meteorological stations, but most are not reported to the World Meteorological Organization's Global Telecommunications Network in near real time, or made accessible to remote sensing scientists seeking to create global, gridded precipitation products. Kenya reports fewer than ten of these stations to the international networks daily, reducing significantly the ability of satellite estimations to capture the actual variability of rainfall within Kenya. Reliance on local provision of observations makes the global dataset vulnerable to significant increases in error when political and economic problems result in a cessation of reporting of rainfall data to global networks. Thus the error structure of satellite-derived rainfall datasets is more related to the political and economic circumstances of the region than it is to any biophysical variable (Brown, 2008).

Despite new satellites that capture precipitating clouds and humidity such as the Tropical Rainfall Measuring Mission (TRMM), satellite-based gridded rainfall data often fail to capture adequately extreme events that may bring much of the rainfall in a season. The TRMM Multi-satellite Precipitation Analysis (TMPA) data product provides rainfall at 0.25 degree spatial grid and three-hourly resolution (Huffman *et al.*, 2007), is a significant advance over previous products and represents the state of the art of satellite rainfall observations. Scheel *et al.* (2011) show a decreasing performance of TMPA with increasing precipitation intensity, resulting in significant errors when calculating cumulative rainfall over a period of a month or more in areas that receive strong precipitation events. Extreme rainfall events are short-lived and of high intensity and are therefore very hard to capture using satellites due to lack of coverage (the satellite is not returning information during the event) and inadequate station data (needed to relate observations to actual rainfall that arrives at the ground) (Scheel *et al.*, 2011). This results in poor representation of extreme weather-related events such as flash floods, landslides and other hydro-meteorological hazards (Scheel, 2012).

Drought monitoring and response

Using satellite-derived rainfall, FEWS NET monitors rainfall in the countries in which they work. Figure 3.2 shows rainfall in Ethiopia for 2011 and 2012 compared to the short-term mean. Rainfall remains a very important and reliable way of monitoring growing conditions, and is easily related across time and space since crops have minimum growing requirements and lengths of season (Verdin *et al.*, 2005). If the rainfall received is below these requirements the likelihood of a failed crop is large even with the diversity of crop types, species and management approaches present in the developing world. It is challenging, however, to maintain comparable rainfall data records across decades due to the need for high quality information from the ground, as was noted above.

Satellite remote sensing of vegetation

Another way of measuring moisture availability and crop productivity is the normalized difference vegetation index or NDVI. Vegetation indices are usually composed of red and near-infrared radiances or reflectances (Tucker, 1979), and are one of the most widely used remote sensing measurements (Cracknell, 2001). They are highly correlated with the photosynthetically active biomass, chlorophyll abundance and energy absorption by plants (reviewed in Myneni *et al.*, 1995) and provide a way to measure directly the impact of moisture and temperature conditions on plant health. NDVI was first developed using handheld radiometers, and its relationship with aboveground plant matter was established by correlating information from instruments to the weight of dried plant material in a grassland ecosystem (Tucker, 1977). The use of spectral vegetation indices derived from the Advanced Very High Resolution Radiometer (AVHRR) satellite data followed the launch of the first operational polar orbiting satellite in 1979 (Gray and McCrary, 1981; Townshend and Tucker, 1981).

The normalized difference vegetation index (NDVI) is calculated as a ratio of the difference of the near-infrared (NIR) and the red bands on a sensor: (NIR − Red) / (NIR + Red). Since vegetation has high NIR reflectance but low red reflectance, vegetated areas will have higher NDVI values compared to non-vegetated areas (Figure 3.3). The longest continuous record of global vegetation observations comes from the Advanced Very High Resolution Radiometer (AVHRR) sensor, which has been flown on operational satellites by the US government for more than 30 years. Because of careful calibration of the AVHRR NDVI dataset, the record allows the current image to be subtracted from the long-term mean, enabling an assessment

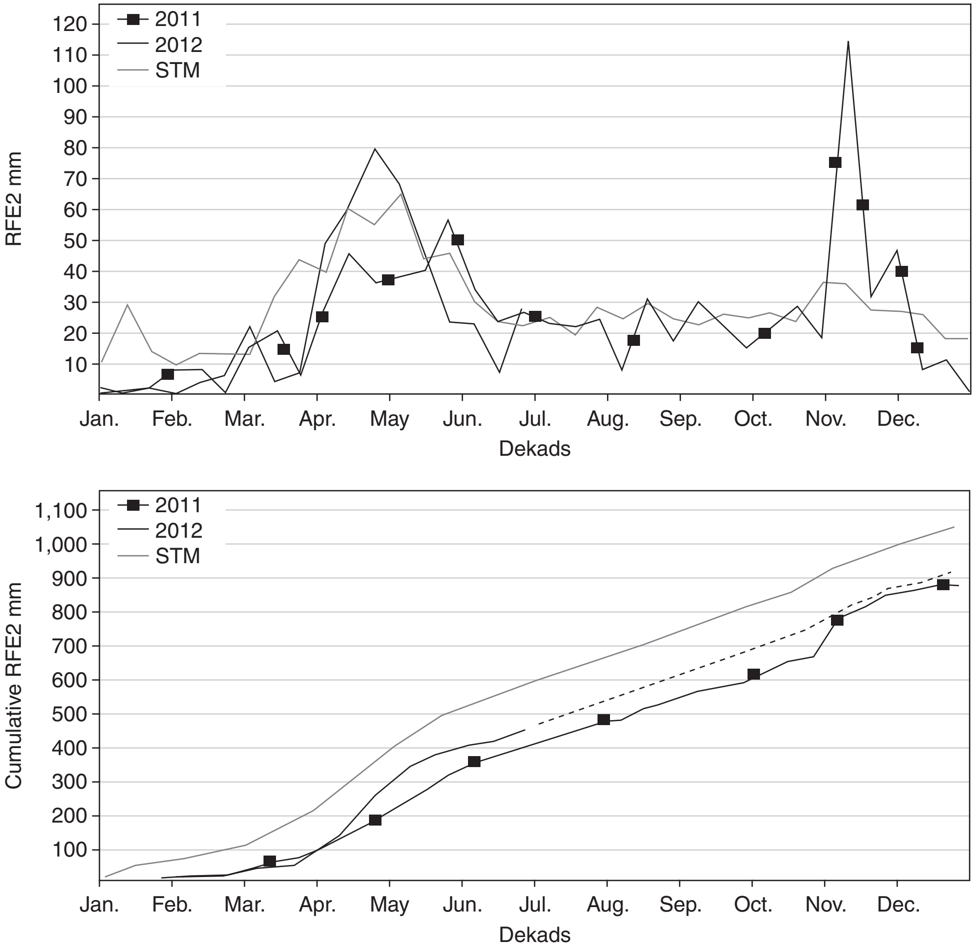

FIGURE 3.2 The ten-day (dekadal) rainfall from NOAA's Rainfall Estimate in 2011, 2012 and for the short-term or five-year mean for Ethiopia's Southern Nations, Nationalities and Peoples' state (source: USGS Early Warning System rainfall data imagery site, early-warning.usgs.gov).

Note

The upper figure shows the time series and the lower figure the cumulative rainfall. The 2011 period had lower rainfall than the 2012 period and both are below the short-term mean. The dashed line shows the rainfall climatology prediction, which is the rainfall for the remainder of the year if current conditions persist.

of how conditions have varied through time. Although the AVHRR sensor has a low spatial resolution of 8,000 × 8,000 meter pixel size, the NDVI data have been used extensively since 1981 to study a variety of global land processes (Townshend, 1994; D'Souza *et al.*, 1996; Cracknell, 1997; van Leeuwen *et al.*, 2006; Neigh *et al.*, 2008; Pettorelli *et al.*, 2011; Brown *et al.*, 2012).

The abundance and greenness of vegetation across the land surface can be seen from space and maps made of its change through time. This is because vegetation pigment absorption, due to the action of chlorophyll decreases reflected red energy, while the reflected near-infrared energy increases. The near-infrared energy is preferentially reflected as a result of the strong scattering processes of healthy leaves within the canopy so that it won't damage the ability of the chlorophyll molecules to function. When the amount of reflected red and/or near-infrared radiation are combined into a vegetation index (VI), the signal representing live, photosynthesizing leaves is boosted and the information becomes more useful (Jordan, 1969). Vegetation indices can then be used as surrogate measures of vegetation health and abundance, including crops, from field to continental scales (Tucker, 1979; Tucker *et al.*, 1985).

Figure 3.4 shows the time series of vegetation from Niamey Niger and from Mogadishu, Somalia from the AVHRR and from the Moderate Resolution Imaging Spectroradiometer (MODIS), both of which collect information in the red and near-infrared regions of the spectrum. Both sensors are commonly used for monitoring growing conditions by food security organizations. Note how the seasonal green-up of the vegetation during the summer wet season and then senescence during the dry season months is clearly seen. Niamey has only one growing season during the summer, whereas Mogadishu has two, one in the spring months and the other in the fall. These data can be used in models that estimate changes in the start and end of the growing season dynamically, as well as identifying periods of drought.

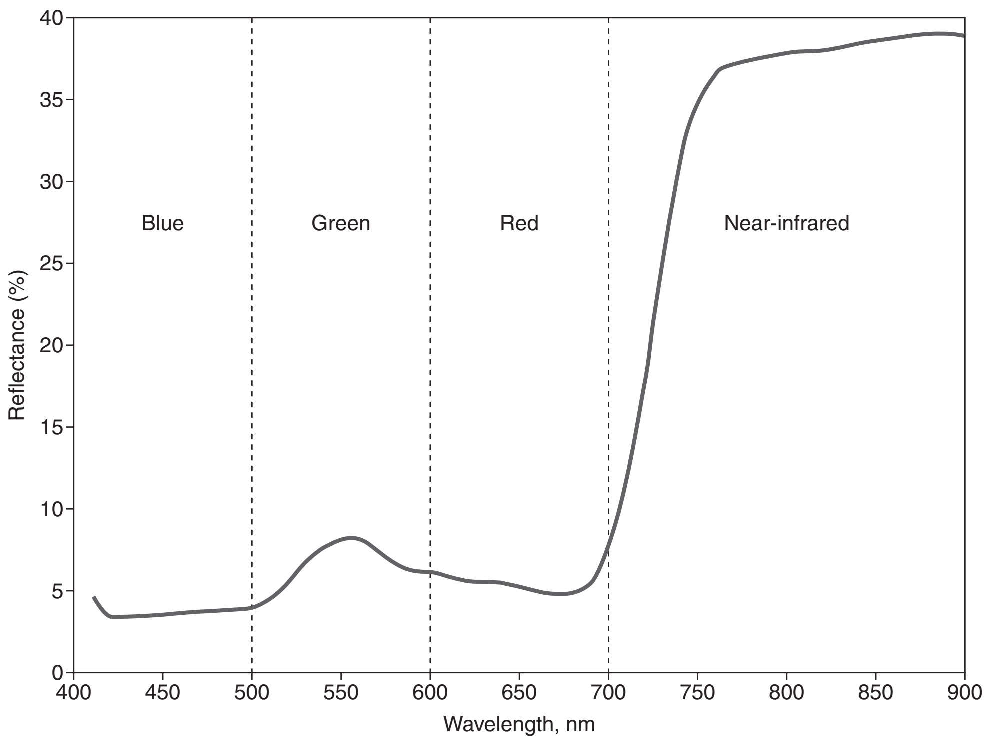

FIGURE 3.3 The NDVI uses the red and near-infrared portions of the spectrum, maximizing the difference between the absorption in the 600–700 nm (red) portion and the reflectance in the 800–1,000 nm (NIR) of the spectrum of healthy vegetation.

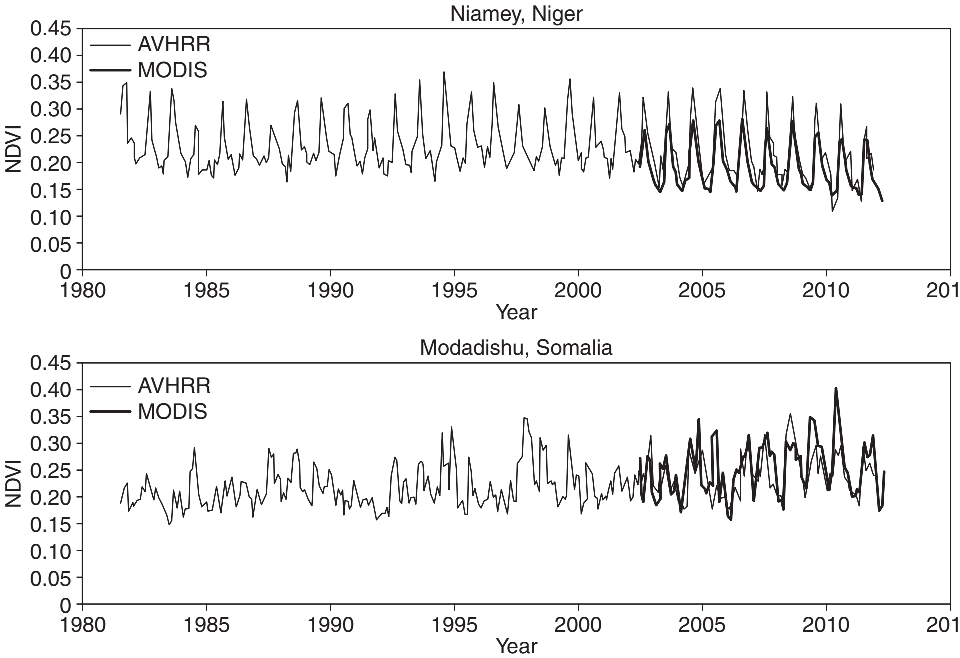

FIGURE 3.4 Monthly NDVI time series plots from Niamey, Niger and Mogadishu, Somalia, showing data from the AVHRR and MODIS sensors.

Note
The AVHRR data are available from 1981 and the MODIS-Aqua data from 2002. Both sensors are still in operation and produce data that can be used for operational drought monitoring.

Unlike rainfall, vegetation data is completely independent of ground observations. Its error structure is related to land cover and cloudiness, with more humid and tropical ecosystems having higher errors due to high amounts of atmospheric water vapor and clouds that obscure the ground during the growing season. Drought-related food security problems are often in semi-arid and sub-tropical ecosystems with low to moderate errors in satellite-derived vegetation data (Morisette *et al.*, 2004).

The Visible Infrared Imaging Radiometer Suite (VIIRS) is a new sensor on operational monitoring satellites that take over the global monitoring task from the AVHRR and MODIS instruments once they become defunct in the coming years. VIIRS data is used to measure cloud and aerosol properties, ocean color, sea and land surface temperature, ice motion and temperature, fires and Earth's albedo. Climatologists use VIIRS data to improve our understanding of global climate change.

Maps that show anomalies can be created from these datasets, identifying areas that may be experiencing drought and that need further examination of potential food security impacts if the anomaly continues (Plate 8). Bringing together information on drought from rainfall data products with those from vegetation can result in a robust estimation of growing conditions anywhere in the world.

Trends in agriculturally relevant growing season parameters

In order to look at the joint effect of temperature and precipitation on growing conditions, many researchers have looked at changes in vegetation phenology. Phenology is the study of periodic biological phenomenon such as emergence, flowering, maturation and senescence of vegetation. Calculating trends in growing season parameters, including the start of the season, length of the growing period and the position of the height or peak of the season, in the primary regions with rainfed agriculture during the past 26 years provides an understanding of how temperature and precipitation have changed during the period. By using satellite data of vegetation dynamics, we can determine if it was moisture or temperature conditions that are most related to agricultural production variations, as this question is a central one for projecting the impact of climate change on food production (Lobell *et al.*, 2008) and identify where the start of season, peak timing and length of growing season have changed.

Estimates of changes in agriculturally relevant start, end and peak of the growing season are based on extensive previous research using vegetation index observations as the basis for measurements of phenological metrics (de Beurs and Henebry, 2010). Many other researchers have worked to integrate remote sensing observations into agriculture applications, including modeling variations in biomass and crop yield, monitoring vegetative stress and drought progression, assessment of phenological phase of crop development, crop acreage and cropland mapping, and disturbances and land use change through time (Atzberger, 2013). These uses of remote sensing data are well established and contribute significantly to our knowledge of agriculture around the world.

Local agricultural production is a key element of food security in many agricultural countries in Africa. Climate change and variability is likely to adversely affect these countries, particularly as they affect the ability of smallholder farmers to raise enough food to feed themselves. Seasonality influences farmers' decisions about when to cultivate, sow and harvest, and ultimately the success or failure of their crops. Jennings and Magrath (2009) described farmer reports from East Asia, South Asia, Southern Africa, East Africa and Latin America. Farmers indicate significant changes in the timing of rainy seasons and the pattern of rains within seasons, including:

- more erratic rainfall, coming at unexpected times in and out of season;
- extreme storms and unusually intense rainfall are punctuated by longer dry spells within the rainy season;
- increasing uncertainty as to the start of rainy seasons in many areas; and
- short or transitional second rainy seasons are becoming stronger than normal or are disappearing altogether.

The impact of these changes on farmers with small plots and few resources is large. Farming is becoming even more risky because of heat stress, lack of water, pests and diseases that interact with ongoing pressures on natural resources. Lack of predictability in the start and length of the growing season affects the ability of farmers to invest in appropriate fertilizer levels or improved, high yielding varieties. These changes occur at the same time as the demand for food is rising and is projected to continue to rise for the next 50 years (IAASTD, 2008).

These farmer perceptions of change are striking in that they are geographically widespread and are remarkably consistent across diverse regions (Jennings and Magrath, 2009), but are based on farmer interviews not biophysical analyses. Long-term data records derived from satellite remote sensing can be used to verify these reports, providing necessary analysis and documentation required to plan effective adaptation strategies with farmers. Earth science can also provide some understanding of whether these changes are likely to continue and their spatial extent.

Early research on the impact of global climate change on the growing season in northern latitudes was based on satellite remote sensing observations of vegetation (Myneni *et al.*, 1997; Nemani *et al.*, 2003; Slayback *et al.*, 2003). These direct observations of change in the onset of spring led to the development of phenological models using remote sensing information. Phenology is the study of the timing of recurring biological cycles and their connection to climate (Lieth, 1974). Phenology, has the promise of capturing quantitatively the changes reported by farmers and providing evidence for their link to climate change.

White *et al.* (2009) described the complexity of comparing ground observations of the start of season with satellite-derived estimates due to the difficulty in understanding the myriad definitions of season metrics. This study compared the different models and methods of deriving phenological metrics from remote sensing datasets, and how the results are strongly related to ground-based phenology and to processes such as changes in snow cover, soil thaw, ice and hydrology. The study highlights both the challenge and potential for integrating remote sensing and ground observations. No other technology besides remote sensing offers wall-to-wall coverage and consistent daily long-term monitoring, yet few metrics of biospheric response are as unconstrained by appropriate ground data on changes in spring onset as those focused on determining the start of season (White *et al.*, 2009). Although the study revealed complexities in the monitoring of growing season land surface response to the impact of climate variability during the relatively short 25-year record used, continued reports from the widespread changes in seasonality drive the need for improved methods and research using remote sensing (de Beurs and Henebry, 2010; Korner and Basier, 2010).

Land surface phenology models rely on remote sensing information of vegetation, such as the dataset derived from the AVHRR (Tucker *et al.*, 2005) and the newer MODIS sensors on Aqua and Terra. Vegetation and rainfall data can assess variables such as the start of season, growing season length and overall growing season productivity (Brown, 2008). These metrics are common inputs to crop models that estimate the impact of weather on yield (Verdin and Klaver, 2002). Phenology metrics have a strong relationship with regional food production, particularly those with sufficiently long records to capture local variability (Funk and Budde, 2009a; Vrieling *et al.*, 2008).

Plate 9 shows a map of the start of season and length of season trends over the 26 years of the start of the season and peak position. This plate shows regions with earlier starts (in red) and later starts (in blue). The bottom panel shows regions with longer growing seasons (in red) and shorter seasons (in blue). Uncertainty in the timing of the agricultural season can be very difficult to adjust to, if communities could previously plan on the rains starting at exactly the same time every year. These changes are likely to have an impact on agriculture, but what the impact is on food security depends on the context in which the long-term trends occur and how farmers manage the changes.

Given the agricultural nature of many developing country economies, agricultural production continues to be a critical determinant of both food security and economic growth (Funk and Brown, 2009). Crop phenological parameters, such as the start and end of the growing season, the total length of the growing season, and the rate of greening and senescence are important for planning crop management and crop diversification and intensification. Research to calculate the average and annual start of season for agricultural areas in all regions is ongoing.

As phenological models are implemented in regions that have temperature controlled, complex, rapidly changing and experiencing much larger climate impacts than in Africa, results will not be as readily explainable as those found in tropical agroecosystems. White *et al.* (2009) focused on North America and did not use agricultural data, they found no evidence for trends that indicated an earlier spring arrival. Using an ensemble estimate from two land surface phenology methods that were more closely related to ground observations than other methods, start of season trends could be detected for only 12 percent of North America and were divided between trends towards both earlier and later spring onset.

There are widespread reports of significant and challenging seasonality changes in many agricultural regions, documenting these changes will require a concerted effort. Establishing consistent plant phenology monitoring networks (e.g., the USA National Phenology Network, www.usanpn.org, or the European Phenology Network) as well as incorporating a broader consideration of non-climatic factors influencing start of season such as land use change, soil fertility and altered crop distribution is therefore critical in improving our understanding of the possible negative impact of climate change on agriculture in the coming decades.

Using phenology to estimate production during a food security crisis

Phenology is not just useful for understanding widespread trends in the growing season, it can be used directly to estimate changes in food production. In 2006–08, USAID needed more information about actual food production in Zimbabwe. A prolonged drought, combined with reductions in cropped area and use of agricultural inputs led to a 55 percent cereal production shortfall (Funk and Budde, 2009b). These reductions, together with the world's highest inflation rate and 80 percent unemployment, led to the dire need of food aid donors to know the appropriate amount of food to send, which required a very accurate food production estimate.

Funk and Budde (2009) used the method to estimate yield and production declines due to weather in Zimbabwe in 2008. The approach focused on yield-vegetation relationships that are typically strongest after mid-season. Rasmussen found that NDVI values from the mid to the end of the growing season in Burkina Faso explained 93 percent of millet yields (Rasmussen, 1992). Authors have taken a number of approaches to increase the correlation between NDVI and yields, most commonly using a simple mask to remove non-agricultural vegetation signals from a time series analysis (Genovese *et al.*, 2001; Kastensa *et al.*, 2005). Funk and Budde (2009) focus on developing a phenologically adjusted, crop masked, NDVI time series analysis to visualize and summarize agricultural performance in Zimbabwe. The resulting analysis showed a strong relationship to agricultural production figures from the US Department of Agriculture, enabling both a spatial and temporal assessment of production (Funk and Budde, 2009b).

This approach was particularly necessary in a place like Zimbabwe due to the recent change in its agricultural regime. In 2006–07, poor growing conditions combined with reductions in cropped area and a transformation of the agriculture sector due to government land distribution efforts resulted in extremely low food production (Scoones *et al.*, 2011). The impact of land reform in the region was complex and diverse, which created a large change in management

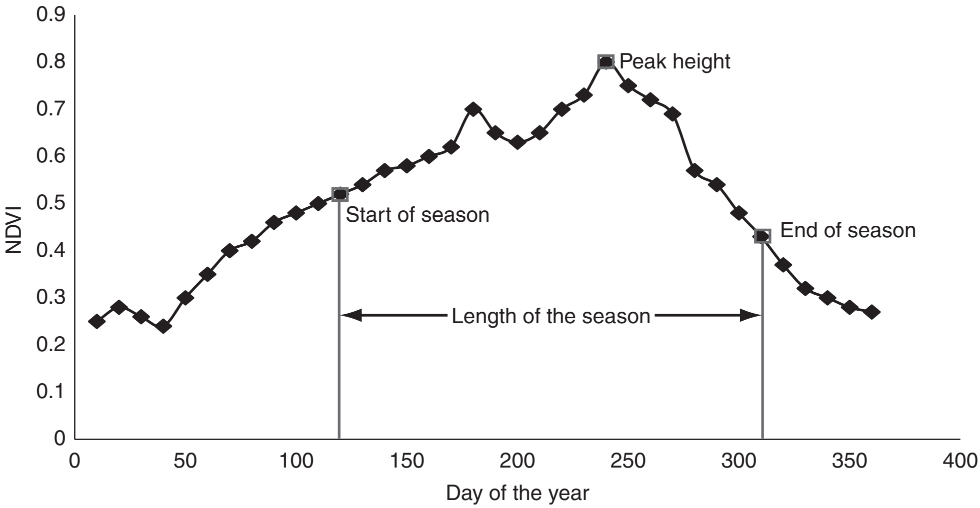

FIGURE 3.5 Phenology metrics derived from models using NDVI temporal curves, including the start of season, end of season, length of season, peak height, peak position in days of the year and cumulative NDVI.

strategies. These changes meant that the methods typically used by food security analysts, that use yield estimate models to assess the *relative* impact of weather on food production, were less useful. For example, the yield model used by FEWS NET is the water requirement satisfaction index or WRSI model (Senay and Verdin, 2002, 2003). It uses rainfall as an input and expresses yield as a percent of normal. If the "normal" or average conditions no longer represent actual production because of a wholesale change in farming practices, then these models are not very useful. Thus the approach taken by Funk and Budde in the 2009 paper was essential as well as effective in providing a new baseline for estimating production.

Phenology and NDVI assessments allow production of national assessments of production deficits halfway through the growing season, which will assist humanitarian organizations with their planning during a crisis. Zimbabwe was particularly ill-equipped to deal with weather-related production declines in 2008 due to its lack of foreign exchange and hostile rhetoric towards the United States and Europe, restricting the ability of aid organizations to assist. Delayed planting date, lack of fertilizer and modern crop strains, as well as inadequate rainfall were the foundations for a significant food security crisis in Zimbabwe in 2008. The analysis that was conducted for FEWS NET using phenology curves from remote sensing data provided a very highly accurate, early and spatially explicit estimate of production when there was considerable uncertainty as to how much aid Zimbabwe would require (Funk and Budde, 2009b).

Socio-economic factors and the impact of climate variability on agriculture

How do socio-economic factors influence how harvests are affected by changes in temperature and precipitation? Although rainfed agriculture is always sensitive to large changes in growing conditions, some regions are more sensitive than others. Recent research has found that factors such as high yielding seeds, use of chemical fertilizer and types of sowing techniques all reduce vulnerability to drought and flooding over large areas, causing some regions to be far more sensitive to changes in precipitation patterns than others (Hansen *et al.*, 2011; Challinor *et al.*, 2007; Simelton *et al.*, 2012).

The 2001 Intergovernmental Panel on Climate Change (IPCC) report defined vulnerability as a function of exposure, impact and adaptive capacity. Underlying socio-economic factors may work to increase the adaptive capacity to withstand droughts, buffering harvests from the effects of adverse weather. Thus the context in which a farmer is working will either enhance or reduce a farmer's ability to withstand climate conditions, affecting the society's overall vulnerability. This is a critical point, since many developed-world economists and analysts underestimate the impact of weather on agriculture, since it is often difficult to relate in a linear fashion the impact of a particular level of drought to a specific reduction in yield. The work done by Simelton and others (2012) brings a level of quantitative analysis to understanding how soil moisture and growing conditions through time affect ultimate production.

Summary

Climate variability and change affects and is caused by agricultural activities at the global scale. Land conversion, forest fragmentation, deforestation and soil degradation at a global scale has had profound effects on the climate due to the domestication of the land surface as the population has expanded. Climate variability, through droughts and floods, continues to have a profound effect on agricultural production despite the use of technology. This chapter explored the interaction between agriculture and growing conditions, through the use of satellite remote sensing and agricultural statistics during the past three decades. All over the world, seasons are changing, starting earlier or later, lengthening or shifting, affecting traditional agricultural systems and management strategies for farmers. The connection between weather and agricultural productivity was explored using country-level analyses, and how these trends are related to climate variability was presented.

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4

TRENDS IN NATIONAL FOOD SECURITY AND THE IMPACT OF CLIMATE

Chapter objectives

Rapid population expansion, coupled with static or declining per capita agricultural production and inadequate growth in alternative economic activities, has resulted in persistent food security problems in many of the world's poorest countries. These trends make countries with a rapidly expanding demand for food much more vulnerable to climate variability, since there are many food insecure people with very little ability to purchase food even in years with above average food production. In this chapter, the objective is to demonstrate how climate variability as measured by satellite remote sensing described in Chapter 3 is likely to affect food security at the national level. Through an exploration of the convergence of trends in agricultural capacity, population expansion and rainfall, a general assessment of the importance of climate variability to food security is presented.

What is national food security?

National food security is defined by the FAO as being a comprehensive picture of the amount of calories available in aggregate for each person in the country (FAO, 2012). Established using "food balance sheets," national food security describes for each food item the sources of supply and its utilization during a specified period. To calculate food supply, total quantity of foodstuffs produced in a country is added to the total quantity imported and adjusted by any change in stocks that may have occurred since the beginning of the reference period. On the utilization side, the food supplies available for human consumption is calculated by removing from the total food available the quantities exported, fed to livestock, used for seed, processed for alcoholic and non-food uses, and lost during storage and transportation. The per capita supply of each such food item available for human consumption is then obtained by dividing the total quantity of available food by the total population using it, and then is expressed in quantities of calories, protein and fat (FAO, 2002).

At the national scale, making these exact calculations of food produced, lost, then traded across borders and consumed is enormously complicated. As FEWS NET states in its review of Zambia's food balance sheet:

> the exact estimation and physical verification of maize stocks held by millers, traders and farmers remains very difficult. There is a need to design a way of capturing grain stock, and capacity utilization information from public and private sectors. There is need to harmonize methodologies employed to capture production figures by the Government and the private sector.
>
> *(Mwila et al., 2004)*

Errors in each of the non-food uses of cereal, such as use of maize in breweries and as livestock feed, can be significant and have a large impact on the final per capita food availability numbers. These problems are greater in countries that are less developed and are more likely to have food security problems. Food balance sheets only depict the amount of food that is available, and say little about other aspects of food security.

Measuring food security is complicated since the concept has multiple dimensions and scales. The previous chapter described FEWS NET's household and community level food security assessment that employed a livelihood context to understand the impact of shocks. The FAO uses a national-level food balance sheet approach to food security assessment that is far more quantitative and less relative than livelihood analysis. Measurement approaches at different scales capture and neglect different elements of food security, influencing prioritization of interventions (Barrett, 2010). Although the FAO can calculate long-term trends because of its quantitative measurement of inputs and outputs, it neglects problems of distribution among a nation's citizens, where some people receive more and others less of the total food available. National food balance sheets feed into policies that favor food aid shipments and agricultural production strategies that may do little to ameliorate these distributional problems, leaving the poorest and most marginalized just as food insecure as before the intervention (Hertel *et al.*, 2007; Sahn and Stifel, 2004).

Changes in food production due to droughts, floods or other weather events affect food availability at the national level, but also impact households and communities directly that are not spatially homogeneous. Weather shocks can completely decimate some farmer's fields, but leave others unharmed. Higher food prices that result can actually benefit the farmers who still have food stocks. Livelihoods analysis and other approaches that use local-level information can improve our understanding of the impact of localized shocks on food security.

Trends in national food security

In its annual "State of Food Insecurity in the World" report, the FAO (2012) estimates that approximately 12.5 percent of the global population, or 870 million people, were undernourished in terms of dietary energy supply in the 2010–12 period. The FAO uses a prevalence of undernourishment indicator, which is based on the food balance sheet approach described above, to estimate food insecurity at the national level. The 2012 FAO report shows that the distribution of hunger in the world has changed over the past two decades, shifting from south Asia to Africa. Table 4.1 shows the change of the number of undernourished, as calculated by the FAO, from 1990–92 to 2010–12. Some regions have seen significant reductions in food insecurity, while others have had less progress.

Although Sub-Saharan Africa was one of the regions where the overall numbers of undernourished have increased instead of declined, the percent of the total population that is

TABLE 4.1 Distribution of hunger in the world

Number of undernourished (millions)	*1990–92*	*2010–12*
Developed regions	20	16
Southern Asia	327	304
Sub-Saharan Africa	170	234
Eastern Asia	261	167
Southeastern Asia	134	65
Latin America and the Caribbean	65	49
Western Asia and Northern Africa	13	25
Caucasus and Central Asia	9	6
Oceania	1	1
World	1,000	868

Source: derived from FAO (2012b).

undernourished has declined. The FAO reports that 32.8 percent of the African population was undernourished in 1990–92 and in 2010–12 the percent is reported to be 26.8. Southern Asia had similar rates of malnourishment in 1990–92, at 26.8 percent, but has reduced the numbers of food insecure to 17.6 percent in 2010–12. There are significantly different capacities to cope with economic and climatic shocks between these two regions that these statistics mask. They are meant to reflect chronic undernourishment, and are not meant to capture short-term changes due to price spikes or other short-term shocks. These shocks, however, occur on top of existing food insecurity, thus looking at trends remains important.

The FAO prevalence of undernourishment indicator is defined solely in terms of dietary energy availability and its distribution at the national level, and does not consider other aspects of nutrition (FAO, 2012). The statistics given in Table 4.1 include the latest world population data, and include new data from demographic, health and household surveys that include revised estimates of food losses at the retail distribution level and for distribution of food within a country. The estimates show that there has been better progress on reducing hunger in the previous 20 years than previously believed, but that economic growth may not necessarily result in better nutrition for all. Policies and programs that provide social protection and increased access to safe drinking water, sanitation and health services will be required to meet the needs of the poorest of the poor (Grosh *et al.*, 2008). Sustainable agricultural growth is needed to reach the poor since many of the hungry live in rural areas and depend on agriculture for a significant part of their livelihoods (FAO, 2012).

Although the large increases in food prices after 2008 had a negative impact, they also created positive incentives for increased investment in agriculture. The impact of the higher cost of the food basket on the poorest parts of a population, many of whom are net food buyers, is harder to see at the national level since improvements in overall calorie availability (or malnutrition rates calculated by the FAO) can occur simultaneously with reductions in consumption by the poorest segments of the population. There are winners and losers whenever there are large changes in the food system. The impact of much higher food prices on food security for poor rural farmers is still unclear, but is likely to be negative unless these farmers can produce enough food to have a significant surplus and have access to the market to sell it (Hazell, 2013; Swinnen and Squicciarini, 2012; Von Braun, 2008).

The impact of high food prices over a period of months or years cannot be easily detected by the methods used by the FAO. They may result in a reduction in dietary diversity of the food consumed, or revert to less expensive but less nutritious foods without changing the overall number of calories consumed. Reductions in other necessary but difficult to track portions of the household budget, such as health care and education, housing and transportation expenses, may also have occurred with long-term consequences but little impact on overall calories. The effect of these shifts in household spending will take time to appear, but are likely to be negative in the long run (Barrett and Bellemare, 2011; Darnton-Hill and Cogill, 2009).

The impact of global economic recessions and food price instability affects some countries more than others (Gouel, 2013). The policy response of the national government to changes in food prices is a critical determinant of the likely impact of these shocks on food insecurity. The countries of south Asia have seen far less impact on food security outcomes from extreme changes in food prices and the global economic recession of 2008–10 than their African government counterparts because of their effective use of macroeconomic policies (Rashid *et al.*, 2008).

Climate and food security trends

Climate variability and climate change are likely to impact every agricultural region in the world, since agriculture is dependent on local temperature and precipitation conditions (Ericksen *et al.*, 2011; IPCC, 2007b). Efficiently producing more food for an expanding population while keeping up with increasing demands for industrial and energy uses of food and fiber will challenge farmers while they are adapting to a changing climate. To explore these large-scale stresses to the agricultural system, the International Food Policy Research Institute (IFPRI) conducted a set of scenarios to explore how food security and climate change are likely to interact in the future. The scenario framework that they state is "still in its infancy" is based primarily on approaches used to understand trends in national dietary energy supply as a proxy for food security. The study team developed three income and population growth scenarios: a baseline scenario which is meant to represent current trends, a pessimistic scenario that while being realistic will result in more negative outcomes for human well-being and an optimistic scenario that will result in more positive outcomes. Each of these economic/population scenarios had five climate futures applied to them, which resulted in 15 plausible potential outcomes for food security (Nelson *et al.*, 2010). Although these scenarios were designed to understand the impact of climate change, they are relevant to our exploration of trends in national food security because they allow an assessment of the relative importance of growing conditions compared to other causes on food insecurity.

The Nelson *et al.* (2010) report draws four main conclusions from their scenario modeling. These are:

1. Broad-based economic development is central to food security and resilience to climate change, as well as to improvements in well-being. Without adequate economic growth, the poorest countries will struggle to provide sufficient calories for its population given resource constraints, and will be more vulnerable over time to climate and food price shocks.

2. Climate change will offset some of the benefits of economic growth. The scenarios show that climate change will cause an increase between 8.5 and 10.3 percent in the number of malnourished children, some of which is due to increased food prices by 2050.
3. International trade plays an essential role in compensating for various climate change impacts at the national level. Thus trade in food allows countries that produce more to offset deficits in regions that produce less, enabling more people to access food than is possible without effective and efficient trade.
4. Properly targeted agricultural productivity investments that enable increased yields in regions with very low productivity can mitigate the impact of climate change and enhance food security. Just as in the past, the model shows that productivity increases can reduce the number of malnourished children by 2050 by 16.2 percent relative to a baseline. By increasing productivity you get more food from the same land, enabling an increase in income and food available for the same number of people, driving down food insecurity (Nelson *et al.*, 2010).

Climate variability is a manageable threat if trends in economic growth continue and investments in increased food production are made now, before increases in temperature and changes in precipitation have significant impacts on yields. As time progresses, the cumulative impact of a changing climate and increasing population reduces the likely ability of farmers to adapt to changing conditions (Nelson *et al.*, 2010).

Trends in global agricultural production

Food security today is affected not only by how much food is available locally, but how much food is grown in all agriculture regions and is available for sale on the international market. When there is abundant food produced for the international markets, world prices for commodities remain low. When demand is greater than supply because of factors such as reduced productivity due to a drought or increased demand due to industrial expansion, then food prices will increase, causing increased food insecurity in market-dependent populations (Nelson *et al.*, 2010).

What trends have been seen in agricultural production globally? During the past 50 years, the world has seen an enormous increase in agricultural productivity, through both increasing yields and increasing area under production. This increase more than outgrew the demand for food from a growing population, stabilizing world food prices for nearly four decades. Productivity has increased in the past through improvement of yields in many regions and expansion of cropped area in lesser-developed areas. Figure 4.1 shows an index that describes how the amount of food produced per capita has changed over the past 50 years. The difference in the trend observed in all agriculture compared to cereals is one we'll explore further in this chapter. Developing countries produce primarily cereals for local consumption and these have seen declining yields in the past decade for many reasons (Pingali and Heisey, 1999).

Changes in local crop production due to climate variability will likely have a negative effect on global food security, since in many less developed nations most food is grown and consumed locally without ever reaching the international marketplace (Lamb, 2000; Schmidhuber and Tubiello, 2007). Increasing disparity in purchasing power among nations will heighten the importance of local production, making it increasingly critical that we understand how changes in seasonality influence agricultural productivity (Brown *et al.*, 2009; Funk and Brown, 2009).

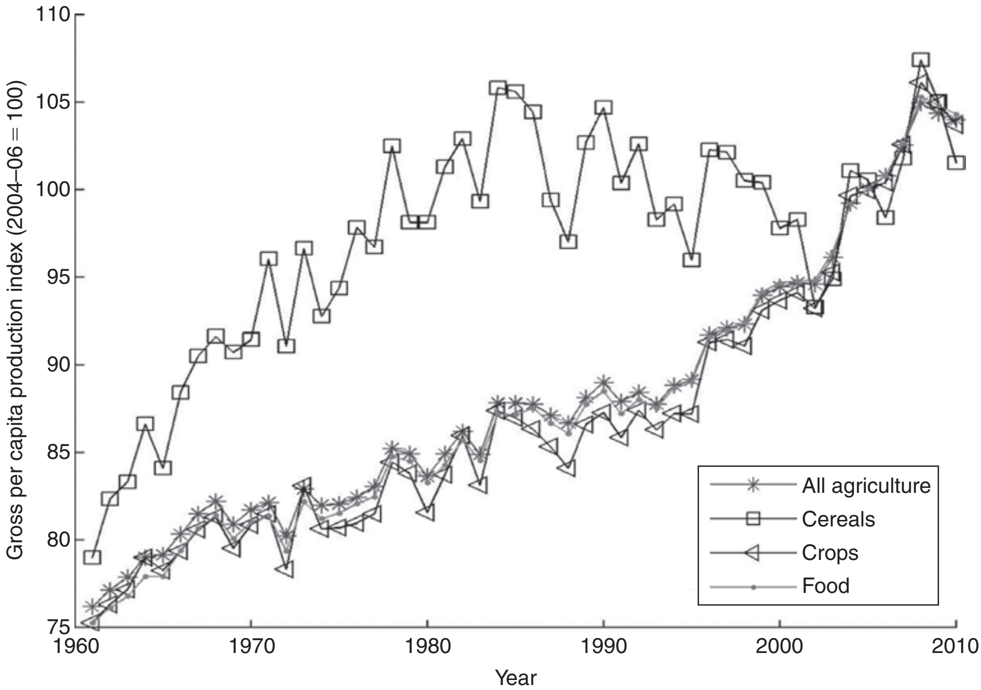

FIGURE 4.1 Gross per capita agricultural production indices from the UN FAO's statistical database, 1960–2010.

Because agriculture produces food, an essential good that all households must have, historically agriculture has employed a large proportion of the population. As the global economy has grown along with the value of goods and services produced that are not in the agriculture sector, the proportion of the overall economy in agriculture has plummeted for developed countries. For example, in the European Union (EU), the proportion of the GDP contributed by agriculture is just under 3 percent. Although this number is very small, agriculture is a principal source of income for around 20 percent of its rural population (Moussis, 2011). Agriculture in the EU accounts for 15 million jobs (8.3 percent of total employment) and a significant proportion of exported goods, since the EU is the world's largest producer of food and beverages. Thus even in developed countries, agriculture and the food sector affects a large proportion of the population.

Figure 4.2 shows the percent of GDP that agriculture provides for most countries in the world. In Africa, agriculture provides around 70 percent of employment and accounts for on average 30 percent of the region's GDP (World Bank, 2010). Although this percentage varies across nations, agriculture is a very important part of the economy in many of the world's nations. India, for example, has nearly 70 percent of its population working in the agriculture sector.

Structural changes that shift the proportion of the total economic production from the agriculture to the manufacturing or to services sector are usually very beneficial overall, as long as the absolute productivity of agriculture sector does not decline. For the purposes of

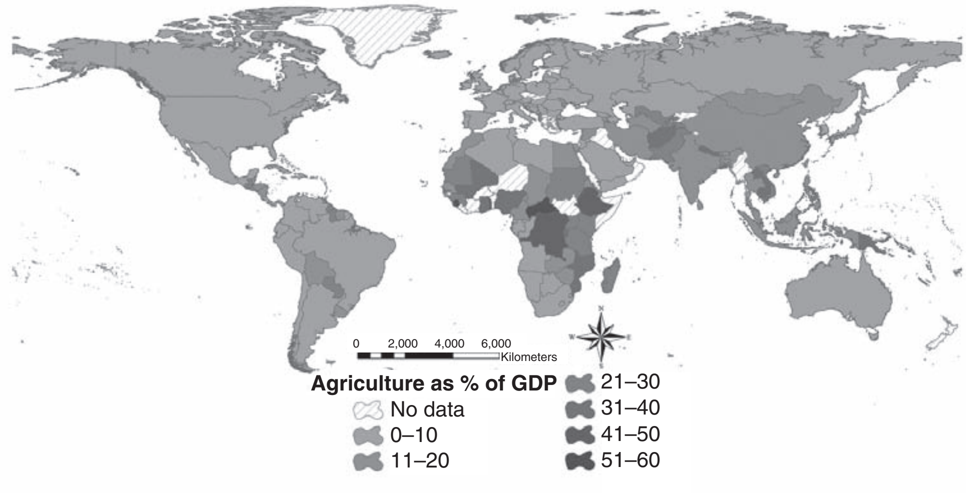

FIGURE 4.2 Value added agriculture as a percent of gross domestic product (GDP) for all countries, average of 2000–10 data (source: data from the World Bank).

analysis of food security, countries with a high proportion of their economy in the agriculture sector are far more vulnerable to climate variability than others with many more diversified sources of income with which to purchase food. They are also far less developed.

If we compare the percent of GDP in agriculture with a metric that describes the purchasing power that a country has in comparison with all other countries, we see a non-linear relationship between income and percent of the economy in agriculture. The gross national income (GNI) is converted into an "international dollar" that has the same value in all places in the year in question (here, 2010). The GNI is the sum of value added by all resident producers plus all net income from abroad (Figure 4.3). Once national income is above around 1,000 international dollars per person, the proportion of the economy in the agriculture sector is usually below 10 percent. GNI is also a useful measure to estimate how challenging a country will find importing food from other regions during times of crisis. The GNI metric describes the relationship between development of the broader economy and purchasing power.

Changes in agricultural capacity in the regions that are most vulnerable to climate variability are a serious threat to food security. Very few developing regions were adequately investing in cereal productive capacity in the 1990s and 2000s due to low commodity prices (IAASTD 2008). The use of improved seeds and fertilizer for cereal production is declining per person in the countries with expanding populations and highly agricultural economies, such as Ethiopia and Tanzania (Funk and Brown, 2009). Since populations have expanded significantly during this period, it has resulted in a reduction in per capita food production during a time when the cost of food has increased.

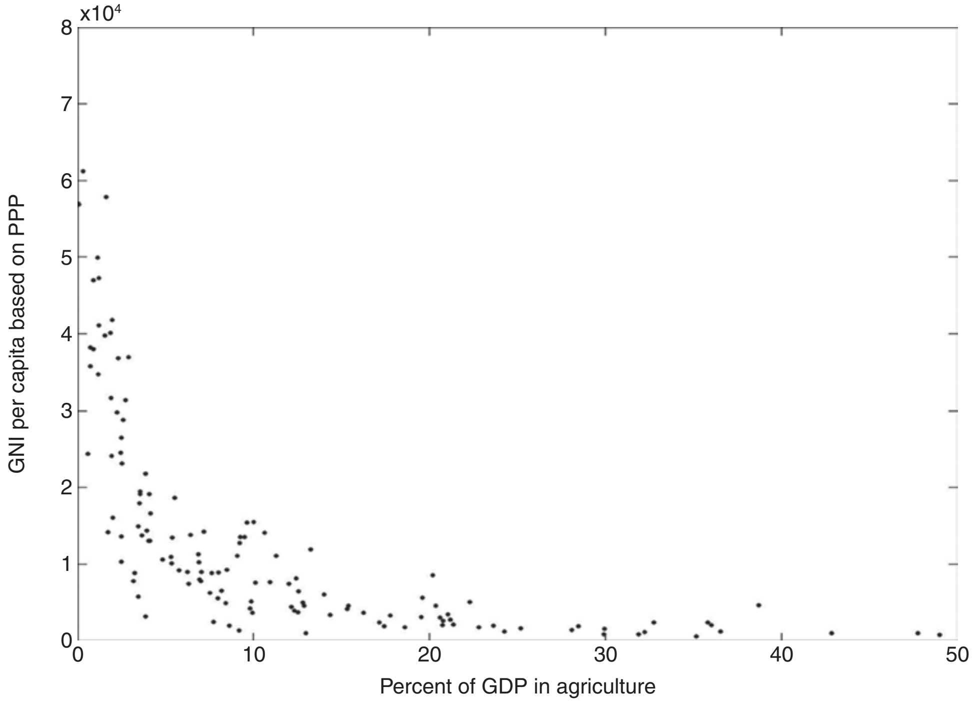

FIGURE 4.3 GNI per capita based on purchasing power parity plotted against percent of the GDP in agriculture for the year 2010 (source: data from the World Bank, data.worldbank.org).

Trends in agricultural land in cultivation

Agricultural production is the product of a particular amount of area under cultivation, multiplied by the yield of the grain per area. How can a global increase in food production be achieved – through increases in yields or increases in area being cultivated? The answer depends on the geographic location and the period of analysis. To achieve increases in yields, farmers must use technology such as chemical fertilizer, herbicides, pesticides and improved seeds that can produce much larger yields than traditional, open pollination crops that are typical in the developing world.

Approximately 11 percent of the Earth's land surface is used for crop production (arable land and land under permanent crops). According to the FAO, this area represents slightly over one-third of the land estimated to be in some degree suitable for cultivation (Bruinsma, 2003). Despite this reality, there is a widespread belief that little more land could be brought into cultivation at the global scale. Bruinsma (2003) points out that this perception comes from the regions that are very land scarce, such as in South Asia, Europe or North Africa. There are other parts of the world, however, that could significantly expand the amount of land under cultivation (Bruinsma, 2003). These regions often have very little infrastructure, are currently forested or are protected to some extent from development. The reality is, in regions with very little access to technology with expanding populations, to increase production, new lands must be brought into cultivation. Areas that have relied particularly heavily on expansion of cropped area are Sub-Saharan Africa, East Asia and South America.

Figure 4.4 shows trends in harvested land area from the FAO statistics database from 1961 to 2010 for Africa, showing the expansion of cropped area in the four major coarse grains. These crops are the least expensive, the most widely grown and most often consumed by the poorest communities. Note the large increase in area planted for maize since 1961, and increases in area planted for millet, sorghum and miscellaneous grains since the mid 1980s, with a nearly doubling of the area under cultivation.

Given that many areas have increased production due to increases in yields, the balance between production gains due to yields and those due to expansion in cropped area is important for understanding how weather may affect production. Climate variability affects yields, but if cropped area is sufficiently large and the surplus being produced is adequate, minimum production should be achievable. Figure 4.5 shows the relationship between total maize production and total harvested area in maize for four regions: Africa, Asia, Europe and North America. Each of these regions has a different production-area relationship, but they all show increases in production. Europe has increased production of maize from 200 million tonnes per year to nearly 750 million tonnes, but farmers in Europe have hardly increased the land in maize cultivation at all since 1961 (FAO, 2013). North America has seen an enormous

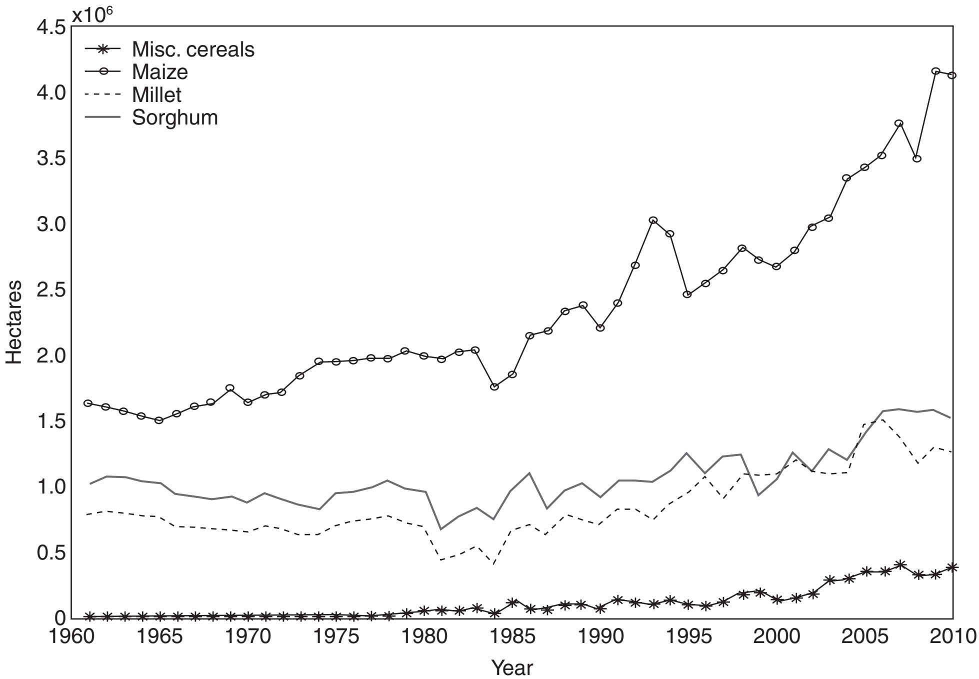

FIGURE 4.4 Trends in area harvested in maize, millet, sorghum and miscellaneous grains for the Africa region from 1961 to 2010 (source: data from FAO statistics database).

Note
Here, the miscellaneous cereal crops category includes grains that are not identified separately because of their minor relevance at the international level.

increase in maize production, with farmers increasing the land in cultivation from 20 million hectares to nearly 37 million over the past four decades. Most of the increase in production from North America is due to increased yields due to increased use of genetically engineered high yielding varieties, fertilizer and herbicides, as well as a huge increase in irrigation.

The Asia region is extremely large and diverse, it also shows an increase in area planted as well as in production, as the adoption of some of the high yielding methods used in North America have increased. Africa, however, has the same levels of production increase as Europe, but much of the increase is due to expansion of cropped area instead of yield. Figure 4.5 shows that although Africa is extremely large with 30 million square kilometers in area compared to 25 million in North America, it could greatly expand both its cropped area and its use of high yielding crop varieties, fertilizer use and irrigation. Gross food production in Africa is, in general, far below other regions given the number of people who rely on local production for their food.

Sustainable intensification, where more food is produced from the same farmland in ways that do not undermine the capacity to continue to produce food in the future, is a policy response to the need to increase food (Garnett *et al.*, 2013). Instead of expanding cropped area to grow more food, intensifying the use of existing farmland enables increased income for farmers who own specific plots of land while producing more food for consumption. Intensification through diverse investments, including conventional high-technology methods,

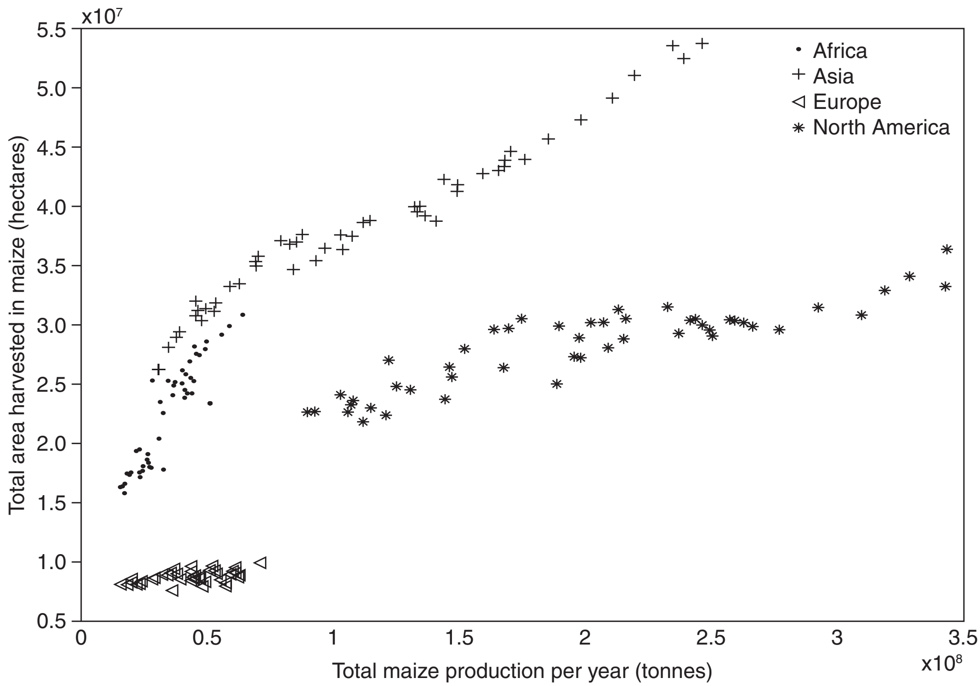

FIGURE 4.5 Scatter plot showing the relationship between cropped area and total harvested area for maize in Africa, Asia, Europe and North America from 1961–2010 (source: data from FAO statistics database).

agro-ecological and organic intercropping approaches, is far more likely to be successful across diverse economic, geopolitical and ecological contexts than a one-size-fits all approach. Agriculture and food production need to be a priority, but investment needs to be done in ways that conform with many other priorities of a food system, including providing culturally appropriate food, employment, economic growth and providing for adequate human nutrition (Garnett *et al*., 2013; Tilman *et al*., 2002).

Observed climate trends using precipitation and rainfall observations

To understand the impact of climate variability on food security, long-term rainfall datasets have been examined for their trends, particularly in food insecure regions. Large changes in moisture conditions can greatly exacerbate any short-term shocks to the food system, since such trends disrupt food production and forces adaptation to these changes by communities over short time frames. Rainfall station data are available in most countries, but must be analyzed in collaboration with local meteorological offices and often need to be digitized and cleaned to ensure quality. By bringing together climate information with the amount of land in cultivation, the trend in agricultural yields that have been observed in the country and the population increase, an assessment of the impact of climate change on food security can be determined. Table 4.2 summarizes the main conclusions from these climate assessments for each country in which they have been conducted.

Climate impacts have recently become of particular importance to broader food security analysis, since in some regions significant trends have been noted in rainfall and temperatures, affecting agricultural productivity. Because these trends are occasionally compounded by increases in population and reductions in agricultural investment and trade networks, trends in climate need to be incorporated into strategies for appropriate response to food security crises.

Analysis of observed climate variability on global crop production

The impact of climate variability on production during the past two decades can be a guide to how climate variability in the near future will likely impact yields and crop production in the next two decades. Global average temperatures have risen by 0.13° Celsius since 1950 (IPCC, 2007a), and the impact this has had on agriculture has been explored by several authors. These studies use yield response models to evaluate the impact of climate trends on major crop yields at the country during the past two decades, and then use the relationships derived to explore how future temperature change may affect future yields.

Lobell *et al*. (2011) presents results that show the total climate impacts depend on the crop and can be disaggregated from negative temperature and precipitation effects and positive CO_2 effects (Table 4.3). Wheat and maize show the largest impact from temperature and precipitation, supported by other studies in France (Brisson *et al*., 2010) and India (Ladha *et al*., 2003). Wheat yields have been particularly affected by temperature and precipitation, leveling off from nearly linear gains over the mid-twentieth century (Lin and Huybers, 2012). Lin and Huybers show, for example, that half of the 47 regions that produce wheat has transitioned to level yields, no longer experiencing increases year over year. With the exception of India, nearly all of these regions are in developed nations including the United Kingdom, France and Germany. The effect of climate and a lack of investment in agricultural capacity are identified as the primary causes of stagnating yields.

TABLE 4.2 Rainfall and temperature changes over the past three decades and their impact on food security

Nation	*Summary*
Chad	• Summer rains have decreased in eastern Chad during the past 25 years. • Temperatures have increased by 0.8° Celsius since 1975, amplifying the effect of droughts. • Crop yields are very low and stagnant. • The amount of farmland per person is low, and declining rapidly. • Population growth combined with stagnating yields could lead to a 30 percent reduction in per capita cereal production by 2025. • In many cases, areas with changing climate are coincident with zones of substantial conflict, indicating some degree of association; however, the contribution of climate change to these conflicts is not currently understood.
Niger	• Summer rains have increased during the past 20 years and have almost returned to 1960–89 levels. • Temperatures have increased by 0.6° Celsius since 1975, amplifying the effect of droughts • Crop yields are very low and stagnant, and the population is growing very rapidly. • Niger has offset very rapid population growth with a large expansion of cultivated land. • If the expansion of farmland slows down, stagnant yields and population growth could lead to increased food insecurity.
Burkina Faso	• Summer rains have remained steady over the past 20 years, but remain 15 percent below the 1920–69 average. • Temperatures have increased by 0.6° Celsius since 1975, amplifying the effect of droughts. • The amount of farmland per person is low, and declining. • Burkina Faso has offset rapid population growth with improved yields. • Continued yield growth would maintain current levels of per capita food production.
Uganda	• Both spring and summer rains have decreased in Uganda during the past 25 years. • The magnitude of observed warming, especially since the early 1980s, is large and unprecedented within the past 110 years, representing a large (2+ standard deviations) change from the climatic norm. • Cropping regions in the west and northwest appear most affected by the observed changes in climate. • Rainfall declines in the west and northwest threaten Uganda's future food production prospects. • Warming temperatures may be adversely affecting coffee production. • Rapid population growth and the expansion of farming and pastoralism under a drier and warmer climate regime could dramatically increase the number of at-risk people in Uganda during the next 20 years. • In many cases, areas with changing climate are coincident with zones of substantial conflict, indicating some degree of association; however, the contribution of climate change to these conflicts is not currently understood.

Ethiopia	• Spring and summer rains in parts of Ethiopia have declined by 15–20 percent since the mid-1970s. • Substantial warming across the entire country has exacerbated the dryness. • An important pattern of observed existing rainfall declines coincides with heavily populated areas of the Rift Valley in southcentral Ethiopia, and is likely already adversely affecting crop yields and pasture conditions. • Rapid population growth and the expansion of farming and pastoralism under a drier, warmer climate regime could dramatically increase the number of at-risk people in Ethiopia during the next 20 years. • Many areas of Ethiopia will maintain moist climate conditions, and agricultural development in these areas could help offset rainfall declines and reduced production in other areas.
Sudan	• Summer rains in western and southern Sudan have declined by 10–20 percent since the mid-1970s. • Observed warming of more than 1° Celsius is equivalent to another 10–20 percent reduction in rainfall for crops. • The warming and drying have impacted southern Darfur and areas around Juba. • Rainfall declines west of Juba threaten southern Sudan's future food production prospects. • In many cases, areas with changing climate are coincident with zones of substantial conflict, suggesting some degree of association; however, the contribution of climate change to these conflicts is not currently understood. • Rapid population growth and the expansion of farming and pastoralism under a more variable climate regime could dramatically increase the number of at-risk people in Sudan over the next 20 years.

Notes

Using quality-controlled meteorological station data from each country, FEWS NET, the USGS and collaborators at the Climate Hazard Group at the University of California have developed climate fact sheets summarizing rainfall and temperature changes over the past three decades and the impact these changes have had on food security. The main conclusions of these publications are summarized here. Copies of each fact sheet can be found at http://pubs.er.usgs.gov/.

TABLE 4.3 Median estimates of global impacts of temperature and precipitation trends, 1980–2008, on average for four major crops

Crop	*Global production average 1998–2002 (million metric tons)*	*Global impact of temperature trend on yield (%)*	*Global impact of rainfall trend on yield (%)*	*Subtotal*	*Global impact of CO_2 trends (%)*	*Total climate impacts (%)*
Maize	607	–3.1	–0.7	–3.8	0.0	–3.8
Rice	591	0.1	–0.2	–0.1	3.0	2.9
Wheat	586	–4.9	–0.6	–5.5	3.0	–2.5
Soybean	168	–0.8	–0.9	–1.7	3.0	1.3

Source: derived from Lobell *et al*., 2011.

Note
Estimates of the 47 ppm increase in CO_2 over the time period.

The positive impact of CO_2 fertilization offsets the impact of temperature and precipitation in some crops, but not in others. It also has no effect on maize yields, which are particularly sensitive to temperature increases. Lobell also creates maps of these changes, showing where the effects of climate are strongest, which could lead to improved adaptation programs. Given the rise in demand for rice and wheat, the reduction in yields due to climate change may have a significant effect on the price of these foods and will impact farmers with a high dependence on this crop.

Of course, climate is only one factor likely to shape the future state of the food supply. Technology change during the period was also a significant driver, which could be identified and disaggregated from climate trends. Lobell *et al*. (2011) divided the observed trends in yields into those that were more related to climate and those that were not. The study showed that environmental trends were able to set back yield gains due to technology for the equivalent of ten years, and had a widespread, spatially coherent impact on yields (Lobell *et al*., 2011).

The impact of climate variability showed a wide variation across countries and regions. As was also found in Simelton *et al*. (2012), lesser developed countries with a high proportion of their GDP in the agriculture sector such as Russia, Turkey and Mexico were disproportionately affected by climate variability. As food becomes more valuable, the incentive to invest in agriculture will grow. For most of the twentieth century, food prices have remained level or have declined slightly. Thus the impact of recent significant increases in commodities has not yet been incorporated into these calculations.

Trends in per capita food availability

To explore the impact of changing rainfall, productive capacity and population, a simple food balance model can be used. This analysis explores the impact of trends in each of these categories to understand how investments in productive capacity might reduce the impact of climate variability. The underlying assumption of this work is that local food production and availability is increasingly important for the food security of a region. Because some regions have significantly lower purchasing power than others, and are likely to continue to have low purchasing power in the decades to come, households in these regions will purchase food grown locally to maintain consumption levels because of the more affordable price of these grains. Although there are significant differences between urban and rural areas in a developing country, in this section we will work with country-level data because that is what is available for sufficient time to calculate trends. The analysis would be stronger if sub-national production information was available for all countries.

To better understand the differential impact of rainfall, population expansion and agricultural capacity in developing countries, a coarse food balance indicator was developed. Presented in Funk *et al.* (2008), the indicator model provides a coarse representation of the impact of trends in these three parameters through time. Agricultural capacity can be described as the amount of cropped area used in agriculture per person, the amount of seeds purchased by the country and the amount of fertilizer applied to the crop. These three parameters can capture most of a country's investment in agriculture and productive capacity. When modified with the amount of rainfall in the main growing season, the indicator model captures national per capita production (Funk *et al.*, 2008).

$$\text{Food Balance Indicator} = \frac{1}{\text{Main Season Rainfall}} \times \frac{\text{Population}}{\text{b1}{\star}\text{Cropped Area} + \text{b2}{\star}\text{Seeds} + \text{b3}{\star}\text{Fertilizer}}$$

The food balance indicator relationship can capture structural food security problems, such as those seen in regions with high levels of population growth, such as is seen in East and Southern Africa. Approximately 65 percent of Africans rely on agriculture as their primary source of livelihood. Small-scale farmers are responsible for more than 90 percent of Africa's agricultural production (IFPRI, 2008).

Figure 4.6 shows the growing gap between population growth and agricultural capacity. Declining rainfall due to climate variability and change will only compound these problems, as it may further reduce agricultural production. Today, one in three children in Eastern and Southern Africa is underweight. The region has a very low national per capita cropped area, leading to very low production even in good years (FAO, 2013). Poor farmers in these countries have become trapped in cycles of displacement, division and degradation (Kates, 2000), and depend on rain fed agriculture to feed their families (Rockstrom and Falkenmark, 2000). Thus in this region, per capita crop production is an important metric of food availability and food security (Funk *et al.*, 2008).

In East and Southern Africa, agriculture capacity trends are dominated by cropped area and population growth increases. Food production has increased by 50 percent over the past 25 years while population has nearly doubled. Extensification into new lands and increased labor inputs have been used to increase production, with investment in improved varieties and fertilizer use lagging (Funk *et al.*, 2008). Since 1990, foreign investment in agriculture has declined from 12 to 4 percent of total aid, and only 4 percent of African public spending goes to agriculture (Lowder and Carisma, 2011). This lack of investment has translated into a reduced per capita agricultural capacity over this time period. Recent increases in commodity prices have once again put pressure on both government and business institutions to increase investment to reverse this trend (Lowder and Carisma, 2011).

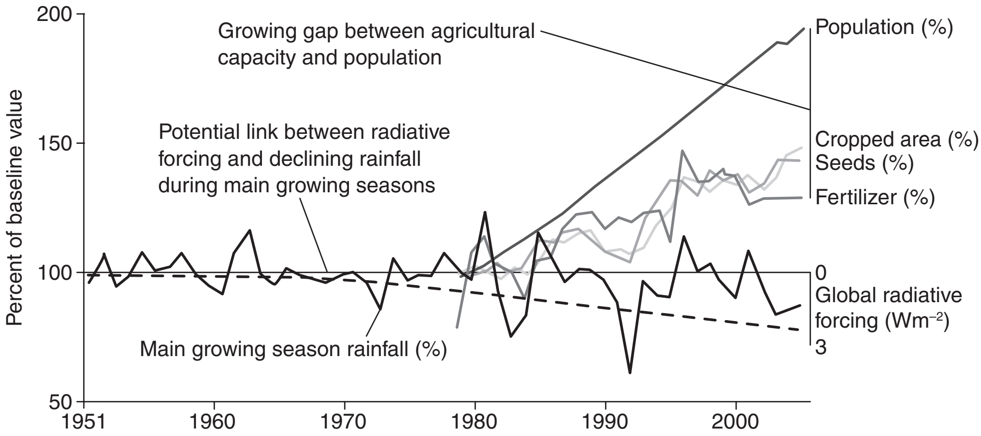

FIGURE 4.6 The growing agricultural capacity gap (source: from Figure 1A in Funk *et al.* (2008) copyright National Academy of Sciences, USA, used with permission).

Note
The plot shows trends in rainfall, population, cropped area, seed use and fertilizer use for eastern and southern Africa. Rainfall is expressed as a percentage of the 1951–80 average. The other variables are expressed as percentages of 1979–81 averages. Global radiative forcing, representing climate change, is shown with a dashed line on an inverted axis.

Model's capability to estimate current food insecurity and projections

Despite its crude formulation, the food balance model expressed above can capture observed FAO observations of the numbers of undernourished people in the Sahel, Southern Africa and Eastern Africa (Figure 4.7). The figure shows that the model is able to estimate the actual number of people in a condition of undernourishment provided by the FAO. The FAO calculates this statistic by estimating the amount of food produced and dividing it with the total population, resulting in the amount of food available for all people. Undernourishment refers to the condition of people whose dietary energy consumption is continuously below a minimum dietary energy requirement for maintaining a healthy life and carrying out a light physical activity.

Although these results look very good, it is important to keep in mind that the FAO calculates its number of undernourished in a similar way to the calculations in the Food Balance Index model. The differences in the inputs and calculations are very small, and thus we are able to reproduce the FAO data quite easily. The FAO is not able to go to each region and, in a statistically rigorous way, measure the actual number of malnourished individuals, thereby deriving the numbers of food insecure independently from broader statistics on food available and population. There are comprehensive nutrition datasets like the Demographic and Health Data that directly measure malnutrition using statistical sampling, but these surveys are conducted only every five years, are not available in all countries and are not used in the FAO statistics. For the purposes of this analysis, however, we are able to capture the interannual variability of the FAO analysis of undernutrition using our model.

Given that the model is able to capture previous variability in the numbers of food insecure, then if we use the model to project into the future, we are able to see how changes in structural food insecurity due to population expansion, changes in rainfall and changes in

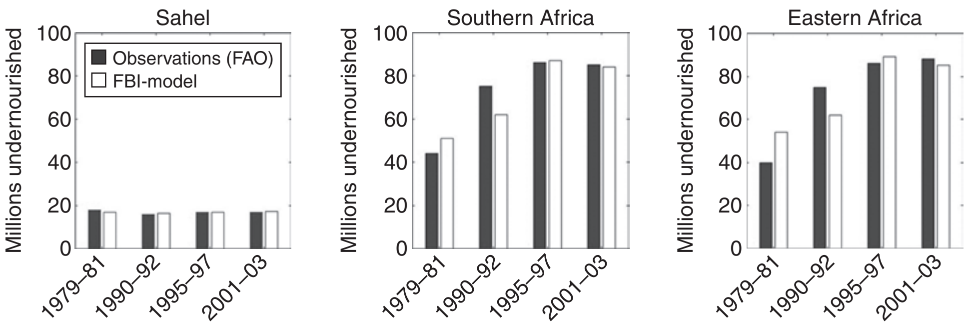

FIGURE 4.7 Comparison of Food Balance Index model output with observed quantities of the numbers of undernourished in each region provided by the FAO from 1979 to 2003 (source: derived from Funk *et al.*, 2008).

agricultural capacity will affect the food security situation. This simple approach is illustrative of the relative importance of each of these elements and how agricultural development could affect the impact of climate variability.

Figure 4.8 shows how the food balance model can be used to project structural food security problems into the future. The figure shows that if population increases and reductions in

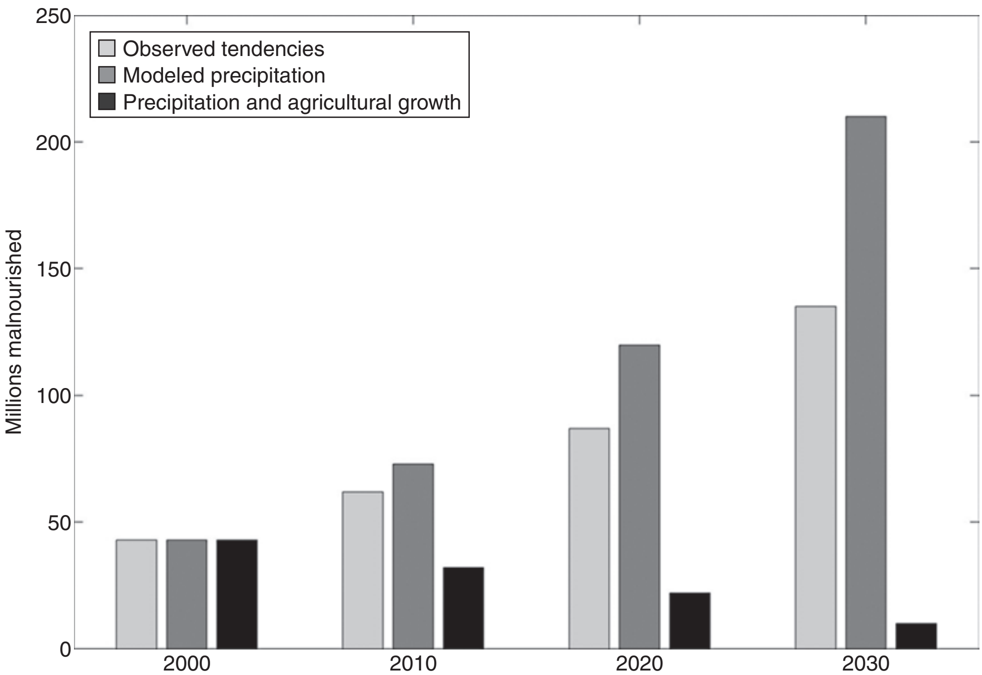

FIGURE 4.8 Food Balance Model projections based on observed tendencies from 1961 to 2008 (Table 4.2) and rainfall projections in the top five food aid recipient countries of Ethiopia, Kenya, Tanzania, Zambia and Zimbabwe (source: Funk *et al.*, 2008).

agricultural capacity in the top five aid recipient countries of Ethiopia, Kenya, Tanzania, Zambia and Zimbabwe continue on the path that they have been on since 1961 (observed tendencies), then there are likely to be 135 million undernourished people in the five countries by 2030. These trends will be exacerbated by reductions in yields due to declining rainfall, increasing the total undernourished to 210 million by 2030. However, if investment in agriculture can increase yields by 15 percent per decade (equivalent to a 2 kg per person per year increase in agricultural capacity), food insecurity in the five countries could be reduced from the current level of 43 million people to ten million by 2030.

There is enormous potential for improving food security by increasing yields and thereby incomes of millions of farmers across the developing world. Increasing the productivity of current farms will be difficult given the many threats to yields, including degradation of soils, reducing access to fertilizer containing phosphorus as the world's supply dwindles (Cordell *et al.*, 2009), increasing climate variability and changes in seasonality. However, it will be far easier to increase food production in regions with low productivity than to increase production in regions that are already highly productive. Figure 4.9 shows yields by region, with many producing far less than their climatic potential. Investment in agricultural capacity, through introduction of high yielding seeds and increased use of fertilizer, will improve incomes for farmers in these regions and increase the ability of the nation as a whole to meet the needs of expanding urban populations.

The food balance modeling approach reported in this chapter excludes trade from consideration. Because the topic of this book is focused on economics and trade, this example may not be ideal. However the model does enable the exploration of the impact of climate variability and population growth on food availability, both of which are critical aspects of price determination in a region. If inexpensive, locally grown food is available in abundance, the likelihood that the poorest members of society could afford adequate food to maintain minimum consumption is far higher than if this is not the case. Thus although the food

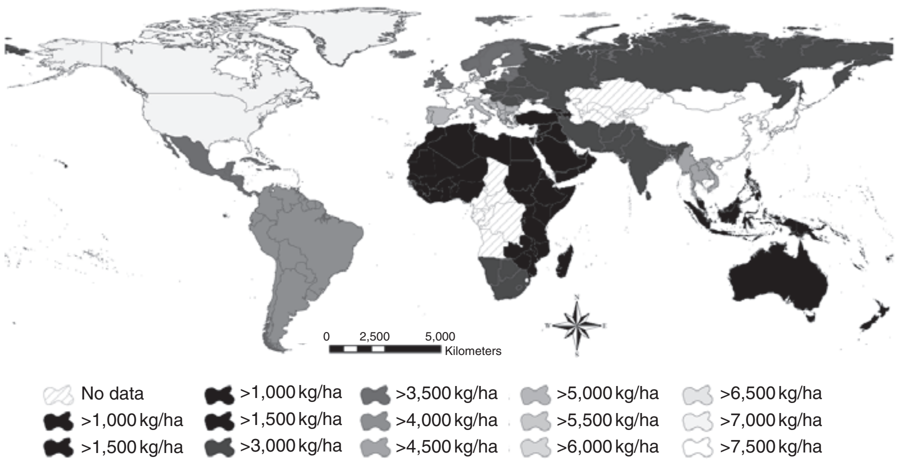

FIGURE 4.9 Map of global yields in kg/hectare shown by region (source: derived from the data in Funk and Brown, 2009).

balance model has significant limitations, it permits explorations of the issues of structural food insecurity.

Purchasing power is the amount of goods and services that can be purchased with a unit of currency. Having money gives one the ability to command others' labor, thus purchasing locally grown food enables households to trade their labor for more food than if they were purchasing food grown in areas with stronger currencies, higher income levels, larger government or other factors that increase costs. As incomes rise, the demand for imported food from outside the region, such as wheat for bread in tropical countries, also rises. The ability to pay for these imported goods depends on the integration of the local economy into the global marketplace. In places like Dakar, Senegal, for example, annual wages of households with office workers are often ten times or more of the annual income of households in rural areas. Although this drives demand for food in Dakar, often the food available for purchase in the city is supplied by the global marketplace due to the change of taste from the grains available in the interior and preferred by rural populations (millet, sorghum) to those available from elsewhere (wheat, rice). The larger the income disparity, the more likely that there is an urban–rural divide in goods consumed (Ruel *et al.*, 2010). Thus within a country there can be considerable heterogeneity among locations – even within a country (and perhaps even within an agro-ecological zone) – regarding the effect of weather on food security, due to the different sources of food for different areas within the country.

Thus to really understand food insecurity and the effect of weather on food prices and food availability, the analysis must not be at the country level. It must focus on individual cities, towns and villages and be set within a particular context. Agricultural products are in reality extremely specific. White corn, grown in Southern Africa, is often lumped with sweet corn from the United States, but the taste, consistency, nutrient balance, protein levels and most importantly consumers of the varieties are extremely different. Although in theory urban consumers in Gaborone can choose between locally grown corn and imported corn on the basis of price, in reality the two products are completely different in the eyes of the consumer.

Food sources and globalization

The role of development in ensuring that all members of a community have enough food for an active and healthy life has long been recognized. The Nelson *et al.* (2010) analysis showed that without both increased agricultural productivity and economic development, little progress can be made in improving the food security of the world's poorest people. Trade is a critical element for food security, one which is difficult to incorporate into food security assessments at the national scale because so little accurate information on trade is available that is relevant to the food insecure. The impact of local climate variability on the food security of a household depends on whether local communities source their food from local production or from national, regional or global commodity markets.

Globalization of food markets is a significant trend that needs to be considered in any assessment of the impact of food prices on food security. Production for domestic use constitutes the largest component of agriculture in developing countries (Von Braun and Diaz-Bonilla, 2008), however some regions are importing a greater share of their food from the international market than ever before. Table 4.4 shows the agricultural trade in terms of total production, with significant trends towards increases in imports and declines in exports.

TABLE 4.4 Agricultural trade in percent of production

	1960s	*1970s*	*1980s*	*1990s*	*2000–02*
Export/production ratio					
Latin America and Caribbean	23.6	24.7	24.5	26.7	31.4
Sub-Saharan Africa (excl. South Africa)	28.5	23.0	17.2	15.3	13.2
Asia developing	5.4	5.7	6.4	6.4	6.4
Import/production ratio					
Latin America and Caribbean	6.7	8.6	11.2	14.0	15.7
Sub-Saharan Africa (excl. South Africa)	8.1	9.4	12.6	12.3	13.5
Asia developing	7.1	8.0	9.2	8.9	8.8

Source: von Braun and Diaz-Bonilla, 2008.

Although Von Braun and Diaz-Bonilla (2008) describe the increase in globalization of the food system, the process has not been homogeneous. Sub-Saharan Africa has become increasingly dependent on imports while reducing the amount of food it contributes to the international markets by half. These indicators, however, may not capture the difference between regions, increased local and regional trade, and production for urban markets that are not captured by national statistics. As mentioned earlier, the statistical expertise and infrastructure required to integrate public and private information on food use and trade requires a sophistication and development rarely seen in developing countries that experience food security crises (Mwila *et al.*, 2004). Relying on quantity indicators for information on the source of local food is problematic.

The FAO 2012 report notes the difficulty of using a national food balance approach to estimate the impact of high prices, since many adaptations to high prices occur at the household, community and regional level. Higher food prices will increase incomes for farmers and spur investment by those with resources. Higher prices also have negative impacts, including short-term hunger, reduction in diversity and quality of food, drastic reductions in other aspects of the household budgets, disinvestment in productive resources, which cannot be measured at the national scale. Globalization and other market integration effects can only really be measured using food prices, comparing local prices to global prices for similar items. In the next chapter, we will explore food markets and their role in providing access to food for households and communities.

Summary

Climate variability is just one of several factors that affect food security and food production globally. This chapter explored the structural causes of food insecurity, including population expansion, changes in land under cultivation and a lack of investment in agricultural inputs such as fertilizer and improved seeds. Observed trends in production, cropped area and yield were explored, and their potential impacts on food security at the national level was discussed. The impact of climate variability on yields was discussed, and the threat of reducing rainfall combined with increasing population. These structural food security problems could be ameliorated with investment in agricultural capacity that could increase production across the region, creating higher incomes and significant development opportunities, particularly in regions with a high percent of the population working in agriculture.

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5

MARKETS AND DETERMINANTS OF FOOD PRICES

Chapter objectives

Food prices are a primary indicator of the ability of a community to access food. As one of the four elements for food security, food access has become increasingly important as world markets are more integrated and shocks affect local markets where the food insecure live. This chapter describes the global commodity markets and the structure of local and regional food markets in the most food insecure nations. The drivers of local food prices are explored to better understand the importance of climate variability and international commodity prices in determining local food prices. The chapter provides analysis of the different ways food prices affect rural and urban communities using conceptual frameworks that analyze how food prices are changing within the global food system. The chapter ends with a discussion of prices in local markets and how many current price indices fail to capture the impact of price changes for the food insecure because they focus too much on prices of imported products in cities far away from where these populations reside.

International corn prices and corn production variability

Corn is an important global commodity and has a significant influence on world food prices because it is used directly for food across nearly all the regions of the world. It is also produced for animal feed, as an industrial input and as a fuel through the production of ethanol. Because it is so widely used, the data on corn prices are some of the most extensive spatially. The United States produces between 30 and 40 percent of the corn exported to the world market, and over 80 percent of all corn produced in the northern hemisphere. Although the majority of this corn is not used for food but is used in industrial processes or animal feed products, US production still has significant impact on world corn prices. Table 5.1 shows the 2011 corn statistics for production, consumption, imports and exports. Of the 280 million tons of corn consumed in the United States, approximately 60 percent is used for animal feed. The US is also a primary exporter of corn to the international market, exporting 41 million tons to countries around the world, with the top five importers being Japan, Mexico, South Korea, the European Union and China.

TABLE 5.1 Top five 2011 Corn production statistics and ranking

Production			*Consumption*			*Exports*			*Imports*		
Rank	*Country*	*MT*	*Rank*	*Country*	*MT*	*Rank*	*Country*	*MT*	*Rank*	*Country*	*MT*
1	United States	314	1	United States	280	1	United States	41	1	Japan	15
2	China	193	2	China	188	2	Brazil	14	2	Mexico	11
3	Brazil	70	3	EU-27	68	3	Ukraine	14	3	South Korea	7
4	EU-27	65	4	Brazil	54	4	Argentina	13	4	EU-27	6
5	Ukraine	23	5	Mexico	30	5	India	4	5	China	5
	World	874		World	864		World	99		World	94

Source: USDA, production, supply and distribution (PSD) database, www.fas.usda.gov/psdonline.

Note
Units are million tons (MT) of grain

In the United States, over 50 percent of the US crop is produced in Iowa, Minnesota, Nebraska and Illinois. Because US production contributes such a large portion of the global commodity prices, it is possible to connect local weather caused production variability to the interannual variability of the corn price. Figure 5.1 shows the annual first differences of US corn production plotted against the first differences of the annually aggregated corn prices from 1969 to 2010. US corn production accounts for 30 percent of the variance of the corn prices, due to the US's large contribution to the world export market. Even with the US providing nearly half of all corn to the export market, there are many other sources of variability in the international corn price, including market speculation, policy changes, trends in production and corn uses over the past few decades. These influences are even more complex at the national and local scale.

Corn price markets have long been volatile, but in recent years the volatility has increased. Recent price increases have been attributed to market inelasticity due to increased demand from use of corn for ethanol production in the United States (Wright, 2011; Abbott *et al.*, 2011). Diffenbaugh *et al.* (2012) have shown that demand from the large biofuel industry in the United States has increased the volatility of US maize markets in the past decade and will exacerbate volatility in the near-term due to climate impacts on food production.

The United States has a cellulosic ethanol standard for gasoline, whose goal is to make renewable fuels cost competitive and on the market. To meet this standard, biofuel factories have emerged that use corn to create ethanol to produce enough fuel to reduce by 20 percent the US gasoline demand by the year 2012 (Schnepf, 2007). A year after the 2007 passage of

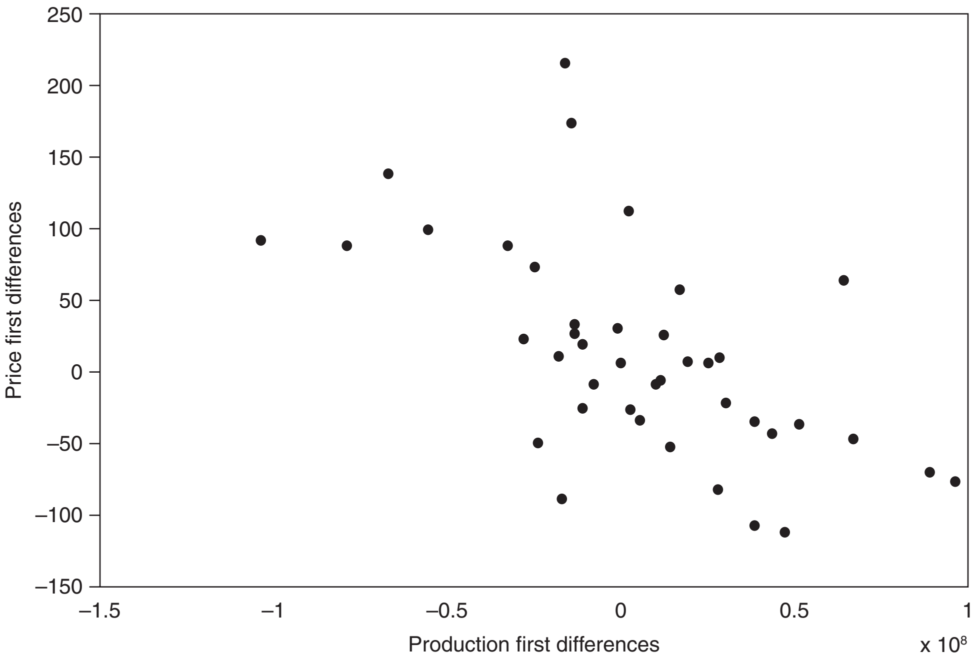

FIGURE 5.1 International corn future prices and US corn production from 1969–2010 (source: price data from IndexMundi and production data from the USDA).

the Energy and Security Act that set this goal, President Bush called for a reduction of 20 percent in US gasoline consumption in ten years. This goal was to be met by setting a Renewable Fuel Standard of 35 billion US gallons (130,000,000 m^3) by 2017 and by reforming and modernizing the automotive Corporate Average Fuel Economy (CAFE) standards (Schnepf, 2007). The impact of this ethanol standard on the commodity market was unintentional, and is often cited as a contributing factor to the massive increase in global commodity prices for many goods in 2007–08, and may be the source of much of the volatility of the maize markets since the imposition of the standard (Diffenbaugh *et al.*, 2012).

Through modeling potential changes in corn production in the US and the price–production relationship, Diffenbaugh *et al.* showed that if a strict, binding biofuels policy remains in place, increasing temperatures in coming decades may greatly increase the volatility of the maize market prices. Volatility in maize production due to increasing temperatures will further exacerbate commodity price volatility. These models, however, only address the direct impact of climate on US maize production and ultimately on volatility of maize export prices.

How volatility in the export market affects local food production depends on the local market structure. Corn prices in Mexico, for example, were affected by the US ethanol market because US food producers started buying Mexican-produced corn when US producers switched much of their acreage to corn varieties used for ethanol production (Wise, 2012). Wise (2012) estimates that commodity price increases in the Mexican food market due to ethanol production has cost about US$1.5 billion from 2006–11. These costs have had a significant negative impact on the poor in net-food-importing countries.

Food access and household food security

How does food price volatility on the global market impact local food access and food security? This depends on the livelihood strategy of the community in question and how vulnerable the local market is to global food price volatility. Despite accelerating globalization, local production remains at the center of how the world feeds itself. Food purchased from the global commodity markets makes up only a fraction of the food available in a region, since only a small portion of all food grown enters the international marketplace. Figure 5.2 shows the role that household food production, off-farm income and the price of food has on enabling access to food. Livelihoods reliant on work in urban or semi-urban areas are more vulnerable to the availability of and access to public services such as environmental and health services due to the higher prevalence of disease vectors and environmental contaminants that can reduce health and nutritional status of family members (Ruel *et al.*, 2010).

Well-fed individuals are far more resistant to illness, whereas inadequate amounts of calories and micronutrients may cause not only malnutrition, but also intestinal disorders, chronic non-contagious illnesses, anemia, micro-nutrient deficiencies and diseases transmitted by food (Chiu *et al.*, 2009). Good nutrition depends on a set of non-food factors such as sanitary conditions, water quality, infectious diseases and access to primary health care. Thus, having an adequate amount of food for consumption does not assure nutritional security (Pinstrup-Andersen, 2009). These ideas can also be termed "health security" and "nutrition security," although they are usually identified and determined by the individual. At the household and community level, adequate food consumption forms the basis of health.

Increasing globalization of food markets and rising urban populations have made food access the main driver of food insecurity in the world today (Eilerts, 2006). Few food security

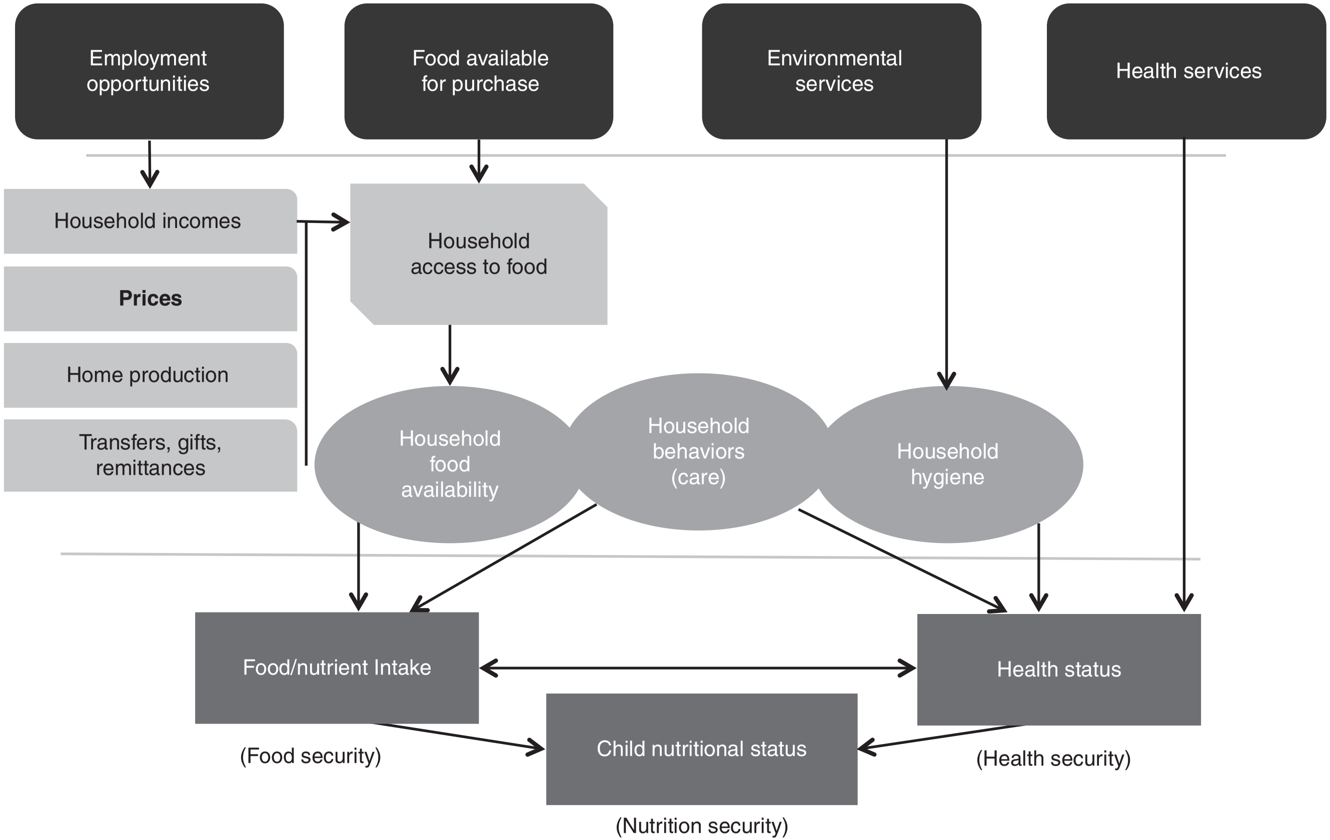

FIGURE 5.2 Conceptual framework of the determinants of food, nutrition and health security (source: adapted from the UNICEF Framework of the determinants of malnutrition, and from Ruel *et al.*, 2007).

crises occur because there is no food available for purchase in markets – only when there is significant disruption of markets and transportation due to an ongoing conflict or political upheaval that obstruct transportation networks is food availability significantly affected (Hillbruner and Moloney, 2012). Food security crises due to inability to access enough food by significant portions of the population are far more common than these types of upheavals. Even during times of crisis, markets are usually full of food that can be purchased – the question is, can the poorest in the community afford to buy it? If the price of food increases far more rapidly than incomes and stays elevated over long periods, the impact on food security is likely to be negative (Von Braun and Diaz-Bonilla, 2008).

Food price levels and volatility

Markets are by far the most common way that people get food. Markets can be western-style grocery stores, little one-room shops where the customer is served through an open window, or an open-air market where goods are displayed on the ground or on tables by product type. The price of food in these markets is affected by a wide variety of factors, including the international price of a commodity, time after harvest, local production deficits and political crises. In very poor regions, the amount of food that each family can buy at one time is very small, thus the number of food sellers is very large, each dealing in very small quantities (Plate 10) (Fafchamps, 2004). This reduces the ability of markets to obtain economies of scale necessary to reduce the cost of food to local purchasers and increases transaction costs (Clark, 1994). Two major factors that affect food access are food price volatility and price levels, or the average price of food over time. Both are important to food security and access, and both are determined by local supply and demand (FAO, 2011).

Price volatility is often measured by the coefficient of variation, which is calculated using the standard deviation of monthly prices over a period of time divided by their mean (FAO, 2011). Prices that are volatile show large changes from one month to the next, or large changes over a period of months. Volatile prices may be either predictable or unpredictable. Predictable changes include regular seasonality of increase and decline due to changes in local supply and demand from the harvest. Another source of predictable variability is a highly variable energy market for petroleum that drives local transportation costs, expenses that may be passed on to the consumer after a delay. With predictability, preparation and appropriate policy responses can be developed to reduce the impact of high food prices on the poor. Predictable changes in food prices have different costs and benefits to local communities than unpredictable changes. Rapid increases and decreases in the price of food reduce the ability of local communities to respond effectively (FAO, 2011).

The level of food prices refers to the relative price of food at a specific time compared to the average food price over an extended period of time. The relationship between local incomes and local food prices is what determines how food prices affect food security. The impact of high or variable food prices depends on the livelihood of the community being affected. If the share of income from agriculture is high, a rise in food prices increases real income, and thus may have an overall net positive effect (Hertel *et al.*, 2007; Panagariya, 2005). Three groups of people can be identified who have different sensitivities to price dynamics:

- Urban consumers who do not produce food and thus increased prices reduce their nominal income (Ruel *et al.*, 2010). The size of the reduction depends on the share of food expenditures in their total spending. In many countries, the poorest third of the population spend more than half their incomes on food (see Figure 1.1).

- Rural net buyers of food buy more than they sell, so higher food prices affect them negatively. In general, this group tends to be the poorest, have few productive resources and earn most of their income from non-farm activities (Egal *et al.*, 2003; Lay and Schüler, 2008).
- Rural net sellers who are able to benefit from higher food prices by selling more food than they purchase, even if production stays constant. The size of the production effect depends on the ability of farmers to produce more in response to higher prices. In many regions where markets are imperfect, the supply response will be low (Von Braun and Tadesse, 2012). If overall inflation in the region is pushed up with higher food prices it may be that this group is unable to increase its income and may even experience a decline in incomes, particularly if agricultural inputs also cost more.

Similarly to different population groups, countries have a differential ability to boost agricultural production in response to higher food price. Countries that are net food importers have had to find new sources of foreign exchange to be able to afford larger food imports. When rapid and significant increases in food prices occur, per capita incomes fall for these poorest segments of the population as the proportion of their incomes spent on food increases further to maintain minimum consumption. These income reductions reduce tax receipts and have an overall detrimental effect on national budgets. Plate 11 shows the difference in resilience to food price shocks across multiple countries.

This recent food price shock affected countries in three ways: those that are resilient, those that benefited and those that were harmed from the increases in prices. The resilient countries saw reductions in undernourishment according to the FAO during periods of increased food prices. Brazil, India and China used a combination of trade restrictions, safety nets and food stock releases to reduce the impact of food price increases on local populations. They were also experiencing large rates of economic growth during this time so incomes were able to keep up with increases in food prices (FAO, 2011).

Countries that experienced a nutrition benefit from increases in food prices are mostly net food exporters like Thailand and Vietnam. These countries have a relatively equal land distribution that permitted expansion of areas under production and further investments in productive capacity. The third group of countries saw increases in undernutrition with higher food prices. This group has very low incomes, and did not have sufficient stocks or budgets to protect the poor from rising food prices. The resulting increase in undernutrition was due to a decline in consumption for the poorest, driven by higher food prices. Many of these countries imported far less from the international market than was actually needed during this period, causing increases in local food prices due to reduced supply. Although the world has seen price spikes before, the global food system is more integrated and income distribution is more unequal with many more poor households net food buyers today than in the past, which means that the recent increases in food prices have had a detrimental impact on food security for billions (Von Braun and Diaz-Bonilla, 2008; Barrett and Bellemare, 2011).

Although it may be too soon to evaluate if food price variability will remain high, it is clear that increase in food price levels has affected many communities. Prices may not return to their pre-2008 levels any time soon. Webb (2010) argues that there are four reasons why it is unlikely that we will be able to anticipate either future price levels or price variability. These are:

1. Increases in food prices in 2007–08 and again in 2010–11 occurred during a time of abundance, not scarcity (Webb, 2010).
2. Record production of cereals and other food was accompanied by a changing distribution of the food insecure in developing countries, many of whom are net food buyers who are sensitive to high food prices (FAO, 2012).
3. Rising food demand occurred after a period of neglected agricultural investment in developing countries starting in the 1970s, that has resulted in declining per capita food production in the poorest countries with the fastest growing populations (Figure 5.3) (Funk *et al.*, 2008).
4. Finally, higher prices for cereals have not translated into higher producer prices for small farmers. Developing country smallholder farmers are reliant on locally available seeds, and have limited access to improved varieties and fertilizer that would boost yields. Although farmers get higher prices at the farm gate for their goods, they also have to pay more for food when their own stocks are depleted. In addition, a large portion of the most food insecure is functionally landless rural laborers or the urban poor who rely almost entirely on the market for food (FAO, 2011, 2012).

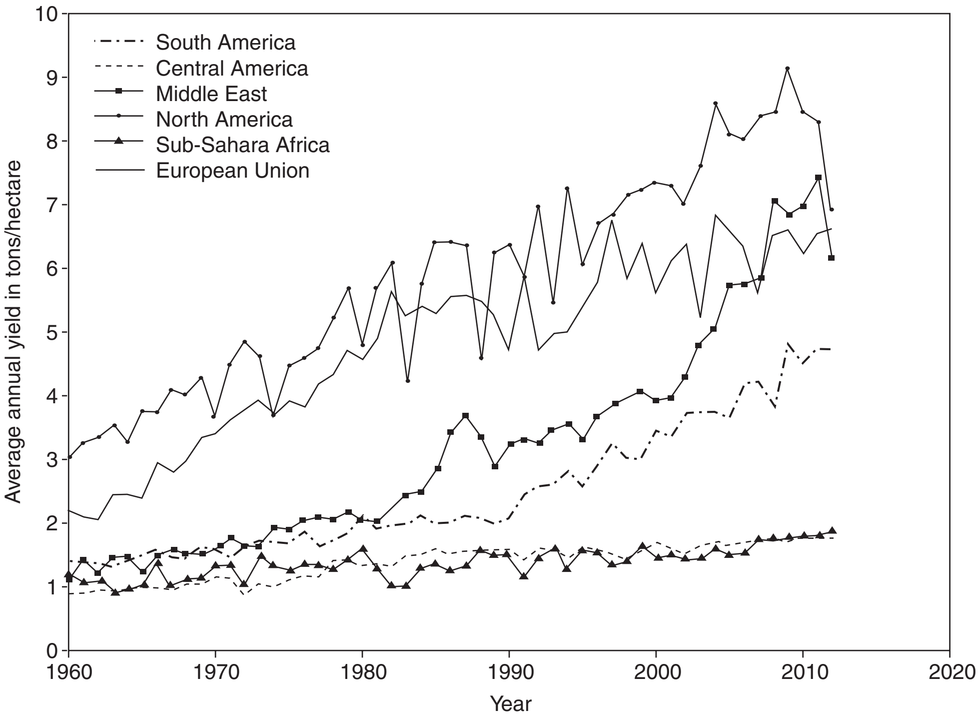

FIGURE 5.3 Global yield increases for maize (corn) that shows that Africa and Central America have not managed to gain from the global transformation of maize productive capacity (source: data from the USDA Production, Supply and Distribution database).

Transmission of high prices from world markets to local households

How do changes in global food prices, shown in Figure 5.4, impact nutrition outcomes in the world's poorest countries? To understand this we must trace the linkages of global price to national, regional and to household and examine how prices are mediated at each stage (Table 5.2). There is a large literature regarding food price transmission, particularly focused on the impact of the recent increase in global commodity prices on food security (Garg *et al.*, 2013; Abbott and Battisti, 2011; Baffes and Dennis, 2013; Baltzer, 2013; Von Braun and Tadesse, 2012; Rashid, 2011). Price transmission happens when two markets that are spatially separated have prices that move together. These movements do not need to be driven by actual physical movement of goods or services, they can also be caused simply by the flow of information (Von Braun and Tadesse, 2012). There are many studies that suggest that recent high food prices have been transmitted strongly to local markets in poor countries (Minot, 2011; Garg *et al.*, 2013; Dillon and Barrett, 2013; Baffes and Dennis, 2013). These transmissions are not complete, with some markets being unresponsive and others reacting in just a few days after the shock occurs (Von Braun and Tadesse, 2012). As Von Braun and Tadesse (2012) point out, "prices in regions characterized by permanent surplus or deficit are more correlated to global reference prices than those in regions with an occasional surplus or deficit." Although it has been shown that price transmission is less complete in African markets than in Asian and Latin American markets, it is difficult to associate local prices with global price changes for the same commodity.

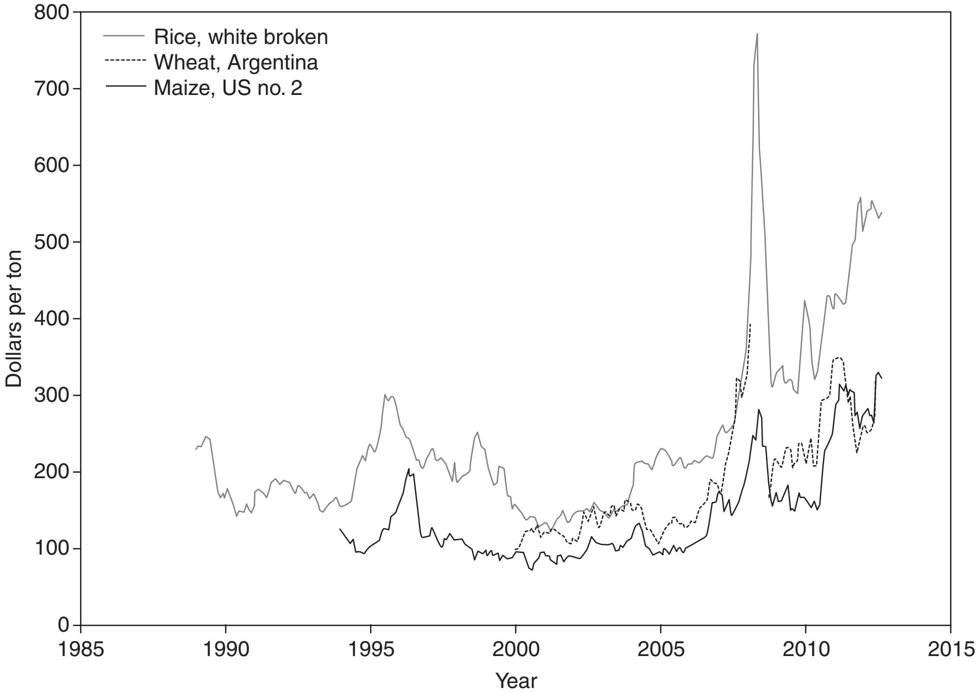

FIGURE 5.4 International commodity prices at major ports for maize, rice and wheat (source: from the FAO Statistical Database).

TABLE 5.2 Mechanisms of transmission of global commodity prices and market status to the impact on the individual

World	→	*Country*	→	*Household*		
Underlying conditions	*Data – at border*	*Underlying conditions*	*Data – domestic*	*Underlying conditions*	*Data (adult)*	*Data (child)*
Food system: trade, transport, processing	Border food prices	Food system, transport, trade and processing	Cost of food at household level	Food consumption and substitution patterns	Dietary diversity	Quantity and quality of food intake
Global cereal prices (maize, rice, wheat)	Trade restrictions tariffs and taxes	Food policies: subsidies and history	Food subsidies and taxes		Division of food in family	Nutritional levels
Exchange rates	Access to commercial ports	Factors in food markets: availability of land, use of agricultural inputs	Availability of food production inputs	Food production, access to land and inputs	Food production for own consumption/sale	Access to health care and education
		Supply and demand for non-food	Cost of other goods	Income generation patterns	Employment, wages, conditions	Child labor
World markets – fuel, commodities, labor		Labor markets: formal and informal employment	Income generation opportunities	Investment in education, health care system, childcare	Spending on non-food	Living and eating at home or elsewhere
		Transportation networks and fuel availability	Education costs	Family, social and community relationships	Savings and debts	Future health and livelihood prospects
Patterns of migration and remittances	Government fiscal position	Financial services	Health and water services	Household assets: land, natural resources, goods	Inter-household transfers and loans	Sense of empowerment and well-being
	Foreign exchange	Government services and budget	Social transfers		Time and expenditure on water and sanitation	
		Social support programs and history			Household and individual assets	
		Previous levels of wealth and assets, equity			Income from transfers	

Source: derived from Compton *et al.*, 2010.

Price transmission is important for food security because food prices have long been characterized by stickiness, or the likelihood that a price reduction spreads to the farm gate price faster than a price increase, and an increase spreads to the retail price faster than a decrease (Von Braun and Tadesse, 2012). Although recent movements in prices spread far faster than in the past, in regions where infrastructure is poor or markets are isolated and not very competitive stickiness may still be an important factor in price movements.

Table 5.2 shows some of the linkages and underlying transmission pathways between global and local prices. There are many feedback loops that are not represented in the table, for example the reduction in demand for a particular good due to the movement of large portions of the population from the high priced, imported food to lower priced substitutes that have different sources. The literature usually assumes "plausible linkages" between food prices and impact, rarely including rigorous studies of actual households, their incomes and individual measures of nutritional status with controls (Compton *et al.*, 2011). Thus many feedback loops that actually exist are missing from this representation, and from a broader understanding of the positive and negative impact of food price variation and level on nutrition outcomes.

The impact of food prices on food security depends on livelihood strategy in the region where the dynamics occur. Although rural households grow food, many farming families have diversified their income sources, working in rural markets, livestock production, crafts and wage labor markets (Abdulai and CroleRees, 2001). Although this has increased cash income and to some extent has also improved the standard of living of these households, it has also driven most subsistence farmers to be net purchasers of food from the market (Brown *et al.*, 2009).

Consumers' responsiveness to changes in prices and in incomes depends on the size of the changes – the larger the price change, the larger the response. In poor countries where the proportion of income spent on food is high, this response to prices is far more significant than in middle- and high-income countries. The responsiveness of food prices to demand was measured in 114 countries and shows that food demand in low-income countries reduced –0.59 whereas in high-income countries it was –0.27 (Seale *et al.*, 2003). Even when consumers compensated for high food prices by increasing their income, their demand response to high prices drops only slightly (ul Haq *et al.*, 2008). The implication for food security of higher prices is thus significant and negative, particularly when food prices move unpredictably (Von Braun and Tadesse, 2012).

Impact of international commodity prices on local food prices

The analyses reviewed above regarding the impact of global prices on local food prices focus almost entirely on internationally traded goods. This makes a great deal of sense, since there is a lot more information for these commodities, they are comparable across markets and the value of the goods is well known. Unfortunately, in food insecure communities, few poor people can afford to eat wheat or rice imported from halfway across the world. The poorest people in the poorest countries eat the least expensive food that provides the most calories, many of which are grown locally, such as cassava, millet, sorghum, cowpeas and peanuts. To understand the impact of high food prices on the food security of these very poor people, we really need to know the impact of global prices on the prices of these locally grown foods. If these local food prices are controlled by variations in the global food system, then it is likely that local production is not a significant source of local food, that local production is not highly variable, that local food is more expensive than food imported from elsewhere or that local foods are not marketed to a significant extent (they are consumed within the households or communities that grow them). Knowing which countries and regions are integrated into the global food system will help food security analysts to identify the countries where high and variable global food prices will cause food insecurity through increasing lack of access, since incomes usually lag behind production.

Another important aspect for calculating the transmission of the international commodity price dynamics to local food prices is determining the importance of local climate variability. If the international price controls local prices, then local food availability dynamics occurs on top of that strong signal. If a drought occurs, what is the impact on food prices and ultimately food demand? This can only be answered through an understanding of locally consumed goods in the market, because if local foods are not marketed and a sudden drop in availability of these foods occurs, a rapid increase in demand in the market may be the result which is likely to increase food prices. Since there are few other ways of tracking local, household food production across large regions remotely at reasonable expense, this attention to food prices of low value, locally grown foods is important.

Food and cereal price indices

To monitor changes in food prices, the United Nation's Food and Agriculture Organization (FAO) has developed a food price index to monitor food commodity price trends at a global level. This index largely reflects supply and demand conditions in export markets in the developed world and the most advanced countries of the developing world. A component of the FAO Food Price Index, the FAO Cereals Price Index, is an indicator of price trends in globally traded cereals but only poorly reflects variations in the least expensive food often consumed by the poor in food insecure countries (Funk and Brown, 2009). Figure 5.5 shows the food price indices from the FAO, including the cereals and the food index. The prices of other important food items are often not highly related to each other, with meat, dairy and sugar showing distinct trends and variability.

The FAO food price index is a normalized, weighted average of prices of a group of goods over a specific period of time. Food price indices are based upon weighted averages of a basket of food items that have documented commodity prices in international export markets and food prices in the capital cities of every country. To deal with multiple currencies, inflation rates, value of currency and many other variables, all price indices are expressed in terms of their value in a base period, and calculated on a monthly basis. Thus one limitation of the FAO food price index is that it relies on generically relevant foods such as meat, fish, dairy, oils, vegetables and grains. For the most food insecure households, nearly all of these goods are not attainable on their very small and stretched food budgets. Thus the food prices included in the food price index are not very relevant to the most food insecure. Thus to understand how the international price of grain affects local food prices, we will use the cereals price index information provided by the FAO.

The FAO cereals index comprises the price of wheat, maize and rice at the international and capital city markets. To take into account the importance of the wheat, maize and rice prices used in the index, the commodities are weighted with world export shares in 2002 to 2004, as provided by the FAO statistical database. Cereal prices are inter-related, thus for the

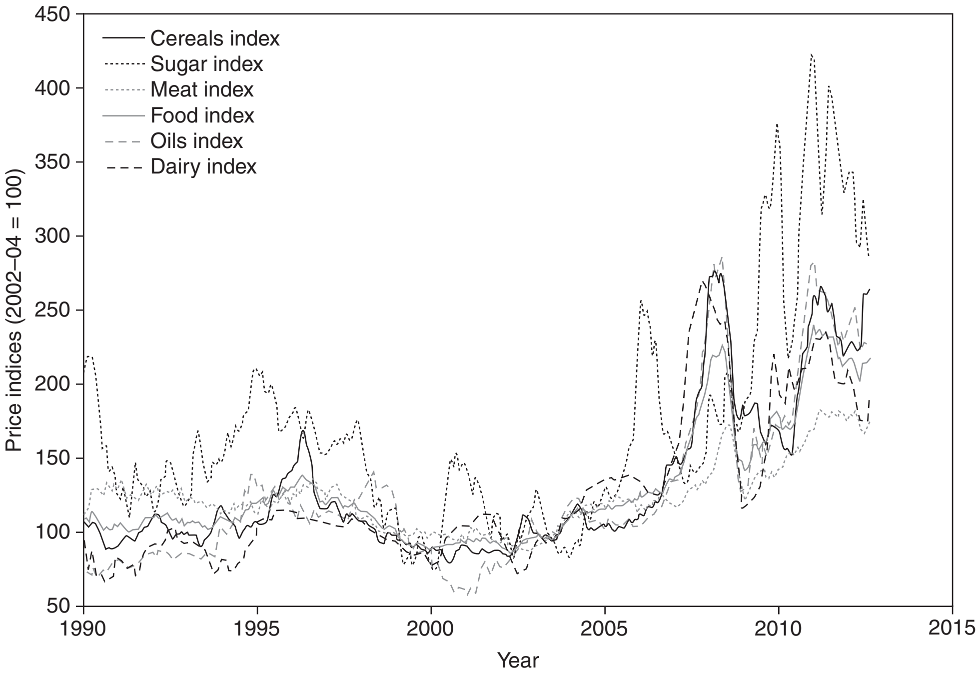

FIGURE 5.5 FAO's food price indices, including food, cereals, sugar, oil, meat and dairy (source: data from the Food and Agriculture Organization).

cereals index, a smaller set of commodity prices than used in these three indices would suffice to observe largely the same general price trends. A regression of month-to-month changes in the FAO cereals price index on month-to-month changes in three export cereal price quotes (no. 2 hard red winter wheat – from the Gulf, no. 2 yellow maize – from the Gulf, and Thai rice 100 percent B – from Bangkok) shows that these three prices explain about 85 percent of the variation in that index (FAO, 2013).

The focus of the analysis is to understand how the FAO cereals index relates to prices of locally grown commodities in small, isolated developing country markets, such as Zinder, Niger. This is a small, remote, rural community situated in the desert margin region of West Africa approximately 150 miles north of Kano, Nigeria. Can we assume that the price in Zinder goes up when the FAO food price index goes up? Since Zinder is a small community of people who mostly are involved in agricultural activities, is information about international price dynamics enough to move local food prices, since it takes months for actual food to arrive in Zinder from the international community? To determine how related local food prices are to global food prices, two elements must be explored. First, we need to determine if the local food consumed is similar to the food consumed by the poorest and food insecure in each country. In West Africa, poor rural farmers raise and eat the grains millet and sorghum, the root crops cassava (manioc) and the legumes cowpeas and peanuts. Most rural households cannot afford to eat imported maize, rice or wheat, the goods included in the FAO cereals index. Thus the mismatch between the locally relevant goods and the goods in the FAO cereals index is a concern.

Figure 5.6 shows the local retail price of sorghum for Zinder, Niger compared to the FAO cereals index. The two time series are poorly correlated, with little relationship between the dynamics of the two series. Of course, this is to be expected since the FAO food index has rice, corn and wheat prices observed in capital cities, and Zinder is not a capital city. But the lack of relationship is striking – what does drive local prices, then? Are all food prices in Niger like that of Zinder? The next section will provide analysis that will answer these questions.

National food price indices for food insecure nations

Prices of staple foods in food insecure regions often do not immediately follow international export market price trends, due to imperfect market integration, prices for local products moving between the export and import parity price bounds, an absence of imported products and/or policy barriers to trade (Minot, 2011; Conforti, 2004). To determine how related the food prices are in any particular country to global price dynamics, we need to create local price indices that mirror those created for globally traded commodities. Once a country-level cereal price index is created, we can assess how related it is to global cereal prices.

To determine the degree of co-movement between prices, economists use regression analysis. The idea behind these time series regressions was that if markets were integrated, then their prices would tend to move together. However, this approach has been criticized since many common components (inflation, climate patterns and population growth) can exert similar influence over prices, even if markets do not trade with each other. At the opposite end of the spectrum, monopoly procurement at fixed prices may result in correlation coefficients of 1.0, regardless of the degree of interaction between markets (Harriss, 1979; Fackler and Goodwin, 2001). Linear correlation also cannot distinguish between markets in which

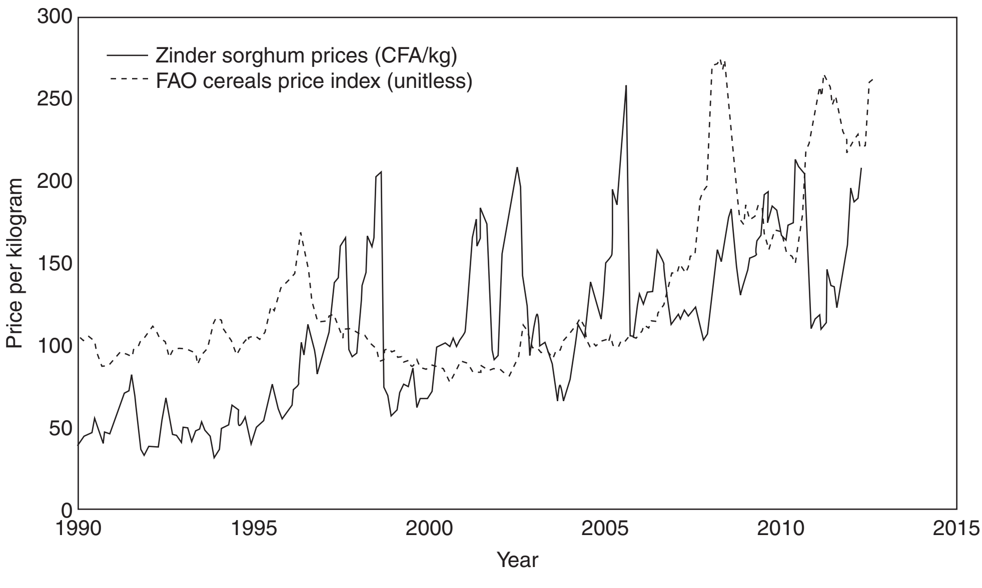

FIGURE 5.6 Plot showing the retail price of sorghum, a locally grown small grain in Zinder, Niger in CFA franc per kilogram, along with the cereals price index, base 2004–06 (source: data from the FAO price database (FAO, 2013)).

there is a lag in the price response between production and delivery of goods at a market (Barrett, 1996).

The Granger-causality metric has been used to study grain market integration in many analyses across the world. If prices, lagged by one or two months, from one market are useful in forecasting prices in another market, even after controlling for own-lagged prices, then the second market is said to Granger-cause price movements in the first. The procedure is usually carried out within the framework of a bivariate regression, a vector autoregressive or error-correction model and confirmed or rejected with an F-test on estimated coefficients. Some analysts have taken the presence of Granger-causality to mean that shocks to prices in one market may induce a significant response in another, with specific time lags. Others have considered it as an indicator of the flow direction of information or goods between markets. Baulch (1997) adds that if two-way Granger-causality exists, then prices are simultaneously determined. Fackler and Goodwin (2001) point out the test only allows inferences about lead/lag relationships and little can be said about the causal framework that underlies the dynamic adjustments (Brown *et al*., 2012).

To produce country-level indices, information was used from a continuously updated price database comprising food prices from 232 markets in 35 countries, collected by the FAO and FEWS NET. Most of the data is publically available from the FAO at the Global Information and Early Warning System (GIEWS) food price website: www.fao.org/giews/pricetool2/. There are several data sources for each country. While a portion of the data can be downloaded from FAO/GIEWS's PriceTool website, not all of the data are available at this public database. While the FAO and FEWS NET use the same data sources (Ministries of Agriculture), and most of the data is publicly available in some form (from newsletters, websites and by request from local Ministries or from the World Food Programme), it is not available from any one source in its complete, constantly updated form, and thus is a unique dataset. There are 124 different commodities in the database from which we draw for the study. FEWS NET experts deemed these commodities as appropriate to assess food security in the selected area. The database has retail price data in local currencies from 1997 to 2011, but the starting year of each series varies by market. The most complete information from 2004 through 2011 is used to form the price indices.

Combining the food price data into indices uses information on local production systems and patterns of food consumption. FEWS NET Production and Market Flow Maps were used to classify markets into major surplus, minor deficit and major deficit zones in each country, creating marketsheds.

The trade flow maps can be found on the FEWS NET website (www.fews.net) under Markets and Trade. For each country and region, the following indices were calculated:

- national cereals price index for 35 food insecure countries, constructed using prices of commodities that are important in the diet of food insecure communities (see Table 5.3);
- regional indices for West Africa, Southern Africa, East Africa, Central America and Central Asia for:
    - cereals only, non-cereals only and all food prices available indices,
    - capital cities only, non-capital cities and all markets indices.

While making the country and regional indices, the number of data observations available from January 2004 to April 2011 was used as a weighting factor for each market and commodity

TABLE 5.3 Summary of price information by country

Country	*All commodities*	*Ave.*[1]	*Std. Dev.*[1]	*Min.*[1]	*Max.*[1]	*Number of markets in index*	*Ave. 2005–09 maize prod.*[2]	*Ave. 2005–09 maize imports*[3]	*Ave. 2005–09 rice prod.*[2]	*Ave. 2005–09 rice imports*[3]	*Ave 2005–09 wheat prod.*[2]	*Ave 2005–09 wheat imports*[3]
El Salvador	White maize, rice (de primera), red beans	129.11	30.42	82.72	196.48	1	764,660	32,788	0	523,930	4,207	227,410
Guatemala	White maize, rice, black beans	131.54	23.97	97.58	168.69	6	1,395,300	27,493	9,082	669,820	1,812	462,950
Haiti	Rice (imported), black beans, maize flour	114.09	21.86	78.84	170.15	5	221,100	116,650	0	8,834	3,342	208,650
Honduras	White maize, classified rice, red beans	133.78	33.12	70.24	204.17	4	545,540	37,628	1,051	304,360	1,924	177,320
Nicaragua	White maize, rice (80/20), red beans	142.04	46.18	63.81	248.43	5	498,010	305,150	0	86,669	3,934	114,980
Afghanistan	Wheat flour, wheat	133.4332	52.92	72.18	285.57	7	322,800	0	3,960,000	1,639	566,800	511,400
Tajikistan	Wheat flour first grade, rice, potatoes	125.95	46.05	53.77	205.24	5	140,740	56,091	701,130	0	0	305,960
Yemen	Wheat, rice, red beans	137.85	36.95	97.62	252.53	1	61,100	0	174,650	364,440	189	2,338,400
Burundi	Cassava flour, maize, sweet potato, beans	120.49	23.65	82.55	175.22	6	121,080	72,019	8,334	23,017	1	6,744
Djibouti	Sorghum flour, wheat flour, rice belem	136.25	37.71	88.72	219.52	6	11	0	0	721	0	123,230
Ethiopia	White maize, white sorghum, mixed teff, white wheat	158.75	76.16	69.62	329.43	13	3,790,400	16,784	2,568,700	42,627	4,122	964,850
Kenya	White maize, sorghum, beans	114.16	28.16	71.12	178.53	8	2,777,600	47,771	315,280	421,370	126,120	652,130
North Sudan[4]	Sorghum	134.13	52.92	58.24	239.6	8	63,400	24,300	623,340	59,714	3,127	1,479,400
Rwanda	Maize, beans, rice	111.77	29.10	54.57	170.62	2	148,710	76,040	41,285	30,283	1,879	9,244
Somalia	Red rice (imported), red sorghum, white maize, cowpea	215.06	134.42	83.48	564.3	21	121,570	17,985	1,016	73,474	0	6,322
South Sudan[5]	Sorghum, maize, wheat flour	145.45	59.12	82.86	346.37	8	–	–	–	–	–	–
Tanzania	White maize, rice	116.59	35.40	55.96	188.21	13	3,418,700	1,279,200	94,720	75,277	45,300	641,430

Uganda	Maize, beans, cassava chips	126.45	48.65	73.2	363.7	5	1,245,600	170,520	18,200	25,437	43,817	356,580
Malawi	White maize, rice, cassava	117.30	44.23	52.78	212.7	9	1,245,600	170,520	18,200	25,437	43,817	356,580
Mozambique	White maize, rice, beans	122.93	39.69	62.78	204.05	9	1,345,800	109,950	2,465	125,770	0	417,150
Zambia	Maize, maize meal	117.04	29.21	75.42	177.98	9	1,351,100	22,314	131,070	40,630	12,882	50,653
Benin	Maize, rice, cowpea	123.91	28.87	79.26	194.25	5	903,650	95,497	0	1,500	9,770	14,723
Burkina Faso	Millet, white maize, sorghum	114.45	26.34	67.68	192.25	6	825,560	136,960	0	4,127	38,570	44,101
Cape Verde	Maize, rice	121.82	25.20	97.64	168.98	1	5,959	0	0	8,412	2,217	22,931
Chad	Pearl millet, maize, sorghum	108.80	24.34	61.46	164.59	6	204,310	132,420	6,515	8,412	0	23,525
Côte d'Ivoire	Rice, yams	114.10	23.47	86.52	190.13	2	615,690	678,770	0	16,642	195,860	302,160
Gambia	Rice	120.66	16.75	99.44	155.33	1	37,536	35,531	0	52	78,474	52
Ghana	Cowpea, yams	176.71	65.48	72.12	321.52	2	1,333,900	283,140	0	46,314	343,800	351,230
Guinea	Rice	93.89	30.68	30.92	173.16	1	632,420	1,409,500	0	2,482	74,863	42,235
Mali	Millet, rice, sorghum	106.51	17.04	73.09	147.23	8	840,640	1,331,300	10,041	7,438	100,890	68,685
Mauritania	Wheat, rice (imported), maize	126.48	19.82	91.19	169.16	6	14,755	72,072	2,198	1,925	64,825	297,280
Niger	Maize, millet, sorghum	110.80	22.14	67.83	182.69	14	5,979	52,085	8,234	28,304	16,079	10,911
Nigeria	Maize, sorghum, cassava, cowpea	124.30	33.95	62.87	213.89	10	6,929,000	3,675,300	54,163	5,613	53,754	3,937,900
Senegal	Millet, broken rice	118.04	23.06	73.75	181.95	5	293,160	314,660	0	102,850	847,130	372,180
Togo	Maize, cowpea	142.11	53.39	65.6	313.2	2	568,140	86,164	0	1,950	28,367	77,675

Notes

The summary of price information by country, includes commodity used in the index, average price, standard deviation, minimum and maximum price during the 2004–11 period, the number of periods in the average, and the number of markets in each country's price index. When there is only one market, it is the capital city of the country. Information on cereals is also provided, including production and import information in metric tons from 2005–09 for maize, rice and wheat, the three commodities in the cereals price index.

1. Average, standard deviation, minimum and maximum statistics of country-index for all food products listed given in price per kilogram per month in local currency over period.
2. Annual production in metric tons, averaged over 2005–09.
3. Annual Imports in metric tons, averaged over 2005–09.
4. North Sudan production and import numbers for all of Sudan.
5. See North Sudan for production and import statistics.

combination, reducing uncertainty in the staple food price indices due to missing information. The commodity price indices were averaged to form a country price index for each country, and a similar method was used to create regional indices. The 2004–11 time period captures more than 75 percent of the price data from 18 of the 35 countries, between 50 and 75 percent of the price data from ten of the countries and between 25 and 50 percent of the price data from six countries. The FEWS NET price indices reflect the average rate of price change for a bundle of key staple cereals that are consumed in each food insecure country.

Results from price index analysis

Plate 12 shows results from East, South and West Africa price indices, compared to the FAO cereals index. The plate shows three series from each region: a regional cereal price index created from markets in the surplus, minor deficit and major deficit zones. Each zone has a different time series and shows variability for each period derived from the spread of price observations among all the markets in each region. The plate shows considerable difference among the regional cereal price index for these three zones.

The plate shows the differences among the surplus, deficit and major deficit regions, and how these are only poorly correlated to the FAO cereals index. The major surplus and minor deficit zones seemed to be more correlated with each other than with the major deficit zones. Examining the time series for East Africa shows a clear lag between the peak cereal prices occurring in the FAO index in 2007 and price increases in East Africa, particularly in the minor deficit zones. West African price indices show much lower variability across markets than the east and southern regions, particularly in the higher price periods. There were many more high prices in the surplus markets in all three markets, six months after the FAO price peak, which were not as pronounced in the major deficit zones. This may be a result of producer prices rising due to the influence of the value of commodities in these regions.

Plate 13 shows the time series of the cereals, non-cereals and all food price indices for each region. In East and West Africa, the cereals and non-cereal prices seem to be very similar. In Southern Africa, the non-cereal prices are far more variable than the non-cereal time series. In Central Asia, non-cereal price series (consisting of locally produced wheat flour and potatoes) are completely unrelated to the cereals time series, and do not show the price increase seen in 2007–08 at all (Brown *et al.*, 2012).

Relationship between FAO cereals and local food price indices

When we take the data shown in Plate 13 and compare it statistically with the FAO cereals index at the regional scale, we are able to determine if a region as a whole is integrated or not integrated into the world market. Table 5.4 shows the results of the Granger-causality test, with local cereal prices in regions that are integrated into the global market shown in grey. The results of the analysis show that in East Africa, wheat, corn and rice are derived from the international markets in the capital and non-capital cities. Non-cereals that are often consumed by the poor are not related to international prices. These non-cereals include mixed teff, sorghum, beans and cassava in East Africa.

The results for Southern and West Africa show that these two regions are not integrated into the international markets. West Africa in particular shows no relationship at all with the international markets, indicating its particularly isolated position in the global marketplace.

TABLE 5.4 Results of the Granger-causality test, presenting the F-test probability for the regional staple food price indices for cereals, non-cereals and all commodities, and for all markets, capital cities only and non-capital cities

All markets

Region	*Cereals*		*Non-cereals*		*All*	
	Granger-caused by FAO index	Granger-causes FAO index	Granger-caused by FAO index	Granger-causes FAO index	Granger-caused by FAO index	Granger-causes FAO index
	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F
East Africa	0.0000	0.2315	0.1512	0.0556	0.0009	0.1395
Southern Africa	0.6836	0.6400	0.0273	0.4985	0.6158	0.6147
West Africa	0.1294	0.1898	0.6521	0.4986	0.2971	0.4735
Central America	0.0115	0.4476	0.0020	0.9730	0.0008	0.5596
Central Asia	0.0005	0.3129	0.5477	0.2181	0.0010	0.1858

Capital Cities

Region	*Cereals*		*Non-cereals*		*All*	
	Granger-caused by FAO index	Granger-causes FAO index	Granger-caused by FAO index	Granger-causes FAO index	Granger-caused by FAO index	Granger-causes FAO index
	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F
East Africa	0.0073	0.0046	0.1698	0.2382	0.0544	0.0702
Southern Africa	0.9421	0.7931	0.1406	0.0795	0.6459	0.5378
West Africa	0.3166	0.1972	0.5557	0.5567	0.2834	0.5671
Central America	0.0059	0.4231	0.0068	0.7433	0.0033	0.5540
Central Asia	0.0007	0.7871	0.4787	0.7283	0.0024	0.5366

Source: derived from Brown *et al*., 2012.

The increase in international commodities in 2007–08 appears to have marked a fundamental shift in the dynamics of regional and global commodity markets (Trostle, 2010; Moseley *et al*., 2010). In some regions, information on prices, adequate transportation, improved ability to sell goods to the international markets and a variable need for importing food from international markets with higher prices have contributed to the variability of local prices (Badiane and Shively, 1998; Deaton and Laroque, 1992; Wodon *et al*., 2008). Central America and Southern Africa show only a small increase in variability over the period of record, but a significant and enduring integration into the international commodity marketplace. East Africa continues also to be integrated into the international markets, but only for cereals and not for non-cereals that may be a significant source of food for the poorest and most food insecure. Southern and West Africa are not integrated into the international markets according to the analysis.

Poorly functioning and poorly provisioned regional markets in Africa are of considerable concern to policy makers. Urban consumers in countries with significant local production of staple cereal crops face a more complex reaction to sharp increases in global cereal prices. Local farmers may be exposed to high food prices without being able to reap the benefit of higher prices in their own marketplace, if they only have a limited ability to produce surplus food and cannot get that food to market without inordinate cost. Consumers may shift to locally produced non-cereal staple foods (e.g., sorghum, millet, teff, cassava, yams, beans) if imported goods increase in price, but this increases the price of these goods locally through increased demand. The result is that these previously affordable goods become more expensive, affecting the food security of the poorest members of the population. In coastal cities where higher prices for globally traded cereals are passed through to the consumer quickly, the impact on these local staple foods is the most rapid. Thus local producers of these non-cereal staple foods benefit somewhat from increased global prices, and consumers are affected by the general rise in all food prices, particularly in the poorest segments of society. It remains unclear if the farmer in subsistence regions will benefit from higher producer prices, or if their exposure to higher food prices because of their inability to produce adequate surpluses will simply increase their food insecurity through higher demands on income.

Brown *et al.* (2012) also present the regression results between the FAO cereals index and the country index, as well as the polynomial least squares regression prediction of local food prices with both the FAO cereals index and the annual NDVI estimate. The results show that in countries that are integrated with international markets, the regression results are significant, and the NDVI unimportant in the results. This lack of significance does not mean that the weather (as reflected in the health of the vegetation) is not important. It may reflect the fact that price information is much more rapidly transmitted down the marketing chain into market prices in these countries. In a sense, it is a sign that these markets are functioning well. On the other hand, when the NDVI is significant, it may mean that information is not completely transmitted down the marketing chain, thus resulting in prices that reflect imperfect information. It is in these countries that NDVI data may greatly aid the food security analyst.

Summary

Previous research has highlighted the negative impact of increasing food prices for the food security of the poor. High food prices have been shown to affect nutrition outcomes through reduced household and individual consumption. As international cereal prices continue to respond to increasing global demand and tight supply, improving the understanding of if and how completely these prices are transmitted to food insecure regions is critical for safeguarding the food security of the poor. When localized droughts reduce food supplies, chronic reductions in food access occur due to elevated prices that can persist over a period of years. Remote sensing information can contribute significant information about local food growing conditions that help identify markets in which prices may greatly affect conditions of food access for the poor.

Staple food price indices developed specifically for food security analysis that include low-value, bulk, semi-processed commodities such as beans, cassava chips and sorghum can inform decision makers in the humanitarian community of the potential for food price-related food insecurity. This information is of increasing value as globalization of the food market begins to increase the transmission of price signals from developed countries into less developed countries, and periodic imbalances between global demand and supply of food is becoming more frequent.

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6

FOOD PRICES AND SEASONALITY

Chapter objectives

This chapter seeks to demonstrate the connection between climate variability and the price of local staple foods through an examination of the reasons for seasonal price movements. The influence of the global commodity markets is discussed, along with other factors that affect local staple food prices, such as changes in marketing or in cereal supplies. As an isolated, poorly developed region, West Africa serves as an example of a region where prices and production are closely coupled. Multi-level, cross-sectional analysis is presented to explain why prices vary across locations. This chapter includes an assessment of how local agricultural productivity as measured by remote sensing is used to improve our understanding of market price dynamics along with economic, political and other shocks on food access. The chapter end with an assessment of social and nutrition impacts of seasonality on children and other vulnerable populations.

Seasonality of food security

Seasonality, or the regular change in the behavior of a system during certain months of a year, is a common characteristic across many climates. Seasonality in the weather, with harvests occurring in similar months across large expanses of a continent, is part of agricultural societies around the world (Devereux *et al.*, 2011). The impact of seasonality in resources, food prices and in food availability has long been recognized and has been extensively described in the literature (Alderman *et al.*, 1997; Chen, 1991; Crews and Silva, 1998; Haddad *et al.*, 1997; Handa and Mlay, 2006; Hillbruner and Egan, 2008). As Devereux (2012, p. 111) states "not only does seasonality generate short-term hunger and seasonal food crises, it is also responsible for various 'poverty ratchets' that can have irreversible long-term consequences for household well-being and for productive capacity in rural areas." Coping strategies that have been developed in response to regular reductions in availability and affordability of food involve transfers of assets from poorer households to richer ones at less than full value (Devereux, 2012).

The challenge of seasonal availability of resources could well be exacerbated by the increasing variability of the climate. Changes in reliability of the start, end and length of the growing season increases the impact of seasonal availability of resources by delaying or disrupting existing coping strategies and increasing the unpredictability of the system. Jennings and Magrath (2009) describe farmer reports from East Asia, South Asia, Southern Africa, East Africa and Latin America. In this study, farmers indicate significant changes in the timing of rainy seasons and the pattern of rains within seasons, including:

- more erratic rainfall, coming at unexpected times in and out of season;
- extreme storms and unusually intense rainfall are punctuated by longer dry spells within the rainy season;
- increasing uncertainty as to the start of rainy seasons in many areas;
- short or transitional second rainy seasons are becoming stronger than normal or are disappearing altogether (Jennings and Magrath 2009).

The impact of these changes on farmers with small plots and few resources can be very significant. Farming is becoming more risky due to increasing heat stress, lack of water, pests and diseases that interact with anthropogenic pressures on natural resources (Moore *et al.*, 2012). Lack of predictability in agricultural production affects the ability of farmers to invest in appropriate fertilizer levels or improved, high yielding varieties. These changes in seasonality occur at the same time as the demand for food is rising and is projected to continue to rise for the next 50 years (IAASTD, 2008).

Farmer perceptions of change are striking in that they are geographically widespread and are remarkably consistent across diverse regions (Jennings and Magrath, 2009), and are based on farmer interviews not biophysical analyses. Long-term data records derived from satellite remote sensing can be used to verify these reports, providing necessary analysis and documentation required to plan effective adaptation strategies to these changes by policy makers (Husak *et al.*, 2013; Iizumi *et al.*, 2013). Earth science can provide insight into whether these changes are likely to continue and their spatial extent (Cook and Vizy, 2012).

Poorly integrated markets, such as those due to an inadequately functioning trading infrastructure, can hinder the functioning of markets, resulting in food shortages (Zant, 2013). Poorly integrated markets are often isolated because of low participation in the market by farmers, resulting in "thin" markets that have too little supply during times of high demand (before the harvest) and too much supply during times with low demand (after the harvest) (Garg *et al.*, 2013). Many households in developing countries seek to be as far as possible self-sufficient in capital, labor and food to reduce exposure to variability in prices and extremely high transaction costs (Lutz *et al.*, 1995). These are both a cause and a consequence of thinly traded, volatile markets. Thinly traded markets keep the difference between producer and consumer prices high, further reinforcing households' incentives to minimize their reliance on markets (Garg *et al.*, 2013; Kirsten, 2012).

Seasonality in food prices in local markets

Not all communities are able to store grain, and therefore experience price seasonality. (Alderman and Shively, 1996). Seasonal price changes may reflect changes in production, particularly in good years when infrastructure and trade constraints reduce the ability of traders to move excess grain out of an area (Devereux, 2012). Seasonal price spreads can be explained by storage losses, large post-harvest grain sales and lack of trader participation in isolated markets during average and good years (Alderman and Shively, 1996). Thus price seasonality is negatively related with production anomalies, where higher (lower) production will create lower (higher) prices during the post-harvest season because of the inability or unwillingness of households and traders to store grain. In general, however, markets that show seasonality in food prices are less well functioning than markets that do not (Kshirsagar 2012).

Beyond variations in the weather, another source of seasonality in food prices in thin markets is the seasonality of transportation costs. Little is known about the variability of transportation costs in each of the markets of this study, but rainfall and poor roads, increased demand for movement of goods and people during the rainy season, and the increased difficulty of distributing fuel and other necessities for transportation make it likely that transportation costs more during the growing seasons (Alderman and Shively, 1996). Transaction costs are the costs incurred in making an economic exchange: determining the price and the demand for a good in a market, the cost of bargaining for a fair price and the cost of policing and enforcement in the market (Asante *et al.*, 1989; Fafchamps, 2004). All of these costs are also likely to be seasonal. These effects taken together mean that without targeted interventions food prices and food availability is likely to be seasonal.

Cornia *et al.* (2012) describes the various government policy interventions that have been used to deal with price increases:

- improving "production based entitlements," or providing subsidies aimed at increasing the amount of food produced and used for self-consumption;
- improving "trade based entitlements," or price stabilization through marketing boards or state-subsidized sales during periods of high prices;
- improving "labor based entitlements" of the launch of public-work schemes that can support household incomes during the lean season; and
- raising "transfer based entitlements" or providing food aid or cash transfers during times of extreme need (Devereux *et al.*, 2008).

The first two of these have been discouraged as a method of dealing with the underlying problem of lack of adequate per capita food production, but the last two have been strengthened (Cornia *et al.*, 2012). The use of food imports to stabilize domestic production during times of rapid price escalation has increased significantly during a period when international commodity prices have also increased, reducing the effectiveness of these interventions (Cornia *et al.*, 2012). The ineffectiveness of local food markets and transportation infrastructure to deliver adequate supplies during times of high food prices can be observed in widespread food price seasonality. Seasonality and high local prices continue to be a significant source of uncertainty and suffering in many least developed countries (Ehrhart and Guerineau, 2011; Hazell, 2013; Kydd, 2009).

High and volatile international food prices, which could provide alternative goods to poorly supplied local markets, make food production a critical component of the economy in food insecure regions. With high prices and significant transportation costs to move grain across long distances, producing more locally will become an important source of vitality for programs focused on reducing poverty (Nin-Pratt *et al.*, 2011; Rakotoarisoa *et al.*, 2011). Sourcing food from agricultural areas within each country keeps the profits from feeding growing urban areas in the local economy, and keeps the cost of living down for both the urban and rural areas. Regions with high population growth will need to continually increase local production to keep up with the demand for food. Without appropriate investment in agricultural seeds and inputs, the region will need to continue to grow its imports to maintain consumption (Bumb *et al.*, 2012).

Exploring the impact of climate variability on food prices in West Africa

An example of the impact of food price seasonality on household food security and nutrition outcomes can be found in West Africa. West Africa is one of the least developed regions, characterized by high levels of poverty, large land-locked countries with poor infrastructure development and a high proportion of the economy derived from agricultural activities. The region is ideal for exploring how climate variability affects food prices, since food is most often sourced locally, the region has poorly developed infrastructure and production is affected by recurring droughts. Francophone West Africa states include Benin, Burkina Faso, Côte d'Ivoire, Guinea Bissau, Mali, Niger, Senegal and Togo. Of these, the Sahelian states of Niger, Mali and Burkina Faso have the poorest access to global markets, have low, erratic rainfall and fragile soils (Heaps *et al.*, 1999). These three countries also have some of the lowest per capita incomes, ranked 199th, 212th and 220th out of the world's 226 countries for Burkina, Mali and Niger respectively (IndexMundi, 2012).

Reliance on agriculture as a primary source of both income and food has led to a fundamental vulnerability of farming households to seasonal and interannual rainfall deficits (Plate 14). Cash income is therefore important because food grown in areas with adequate rainfall can generally be purchased even if grain cannot be grown locally in some years (Mishra *et al.*, 2008; Rojas, 2007; Zaal *et al.*, 2004). The impact of changes in food production and food prices on human health and food security depends entirely on the level of development and government support for the poorest segments of the population.

Rural households in most of the Sahel grow sorghum and millet on their farms and sell grain in order to obtain cash for household needs (Jayne and Minot, 1989). Cereal production in West Africa has increased by 4.4 percent per year from 1980 to 2009, a growth rate that is only marginally above the population growth rate. About two-thirds of this growth was from expanding cropped area, with the rest from increased yields (Bumb *et al.*, 2012). Farmers typically sell a portion of their crop on the market directly after the harvest when the price is low, save a portion for consumption and purchase food from the market as their own supplies diminish later in the year, usually at a higher price. These transactions occur within five kilometers of the household's land because transportation is both expensive and unreliable and food marketing only marginally profitable in small volumes (Platteau, 1996; Zant, 2013).

A key reason for these low increases in yields over the past three decades is the lack of use of chemical fertilizer and other modern inputs, which boost yields in other regions. Agriculture in West Africa grew at half the rate it would need to over the past ten years for achievement of the Millennium Development Goal of halving hunger and poverty by 2015. Bumb *et al.* (2012) describe the challenges that smallholder farmers in the region have in accessing modern agricultural technology, including high yielding seeds, fertilizers, water harvesting and improved agronomic practices. Yields for most crops have the potential to double with greater intensification of inputs (Nin-Pratt *et al.*, 2011). Only 25 percent of all planted area uses improved seeds and a low 8 kg per hectare use of fertilizer. One reason for the low adoption of fertilizer in the region is because of the very high cost of financing, credit and government taxes, greatly increasing the cost per ton over its basic production cost (Bumb *et al.*, 2012). The same constraints that restrict the import of fertilizer into small, remote agricultural regions also reduces the export capacity of farmers and reduces the likelihood that traders will bring food in during times of high local prices.

West Africa is very dependent on local production of a variety of staples, including yams, cassava, millet, sorghum and other native crops that produce food reliably but with very low yields in the tropical soils and rainfed agricultural conditions found in the area (Tadele and Assefa, 2012). The population of the region has tripled from 1965 to 2007, and cereal consumption has followed that growth. Local production has been unable to keep up with the demand, increasing the proportion of food derived from imports instead of local or regional production (Nin-Pratt *et al.*, 2011). The percent of imported food went from 5 percent of total food consumed in the 1960s to 23 percent in the past ten years (FAO, 2013). Although trade profiles vary across the region, cereals, fish and sugar were some of the most commonly imported items. In general, however, there remains a wide gap between the region's production and consumption. The region has not been able to meet its internal demand for cereals. This lack of supply means that the region is vulnerable to seasonal and interannual stress on the price of food, and is vulnerable to weather shocks.

Seasonality in West Africa

Food price seasonality, coupled with volatility in production and a stagnating per capita productive capacity, significantly affects food security in West Africa. Every year from May to September, food prices increase from 50 to 200 percent over dry season means, depending on the year (Cornia *et al.*, 2012). Figure 6.1 shows the annual price increase for retail sorghum, a frequently consumed coarse grain in the small northern community of Zinder, Niger. The seasonality of the prices, increasing each year and then declining, can be clearly seen. This seasonality means that during the growing season in July and August, the price of sorghum is significantly higher than in the dry season (Brown *et al.*, 2006).

Seasonality in food prices is important because it occurs typically during the growing season when farming households have exhausted their store of grain from the previous season and have to come up with cash to purchase staples on the market at higher than average prices. Cash is often borrowed at high interest rates during these months, and must be paid back after the harvest, forcing the household to sell its excess grain at much lower prices than can be obtained later in the year (Brown *et al.*, 2009). The widespread increase in demand in a farming region during the growing season pushes prices upward to their highest intra-annual levels. The hunger season also corresponds to the period when farmers have their highest energy expenditure and all household members participating in agricultural work need more calories than normal (Cornia *et al.*, 2012; Sahn, 1989). Food security is therefore significantly affected because of these seasonal cycles.

As per capita farming income declines and households diversify into more cash-earning livelihoods, exposure to food price variability increases. While food markets are becoming more integrated across more areas, annual and interannual variations in local food prices are still large due to constraints in the production system and inefficiency in distribution in the small, isolated and informal markets that are typical of the region, food prices are intimately

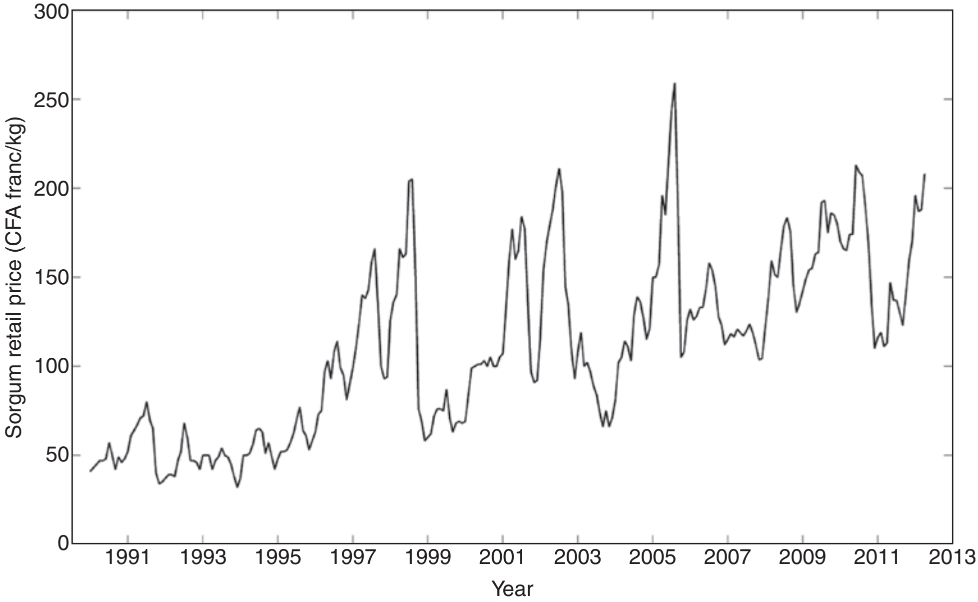

FIGURE 6.1 Seasonal price dynamics from 1990 to 2012 in Zinder, Niger for retail sorghum, a widely grown coarse grain (source: data from FAO Price database).

linked with local food production (Brown *et al.*, 2012; Garg *et al.*, 2013; Von Braun, 2008). Multiple variables can affect the production of cereal crops, not just whether or not adequate rainfall is received. These variables include area planted, insect and animal damage, soil erosion, soil infertility and damage due to wind among many other factors (Hoogmoed and Klaij, 1990; Klaij and Hoogmoed, 1993). International food trade, production imbalances between different areas of a country and limited road networks may also influence the local prices of food (Brown *et al.*, 2013; Cutler, 1984; De Waal, 1988; Deaton and Laroque, 1996).

Rural households in most of the Sahel sell grain in order to obtain cash for household needs (Jayne and Minot, 1989). Farmers typically sell a portion of their crop on the market directly after the harvest when the price is low, save a portion for consumption and purchase food from the market as their own supplies diminish later in the year, usually at a much higher price. These transactions typically occur within five kilometers of the household's land because transportation is both expensive and unreliable (Platteau, 1996). Reliance on agriculture as a primary source of both income and food has led to a fundamental vulnerability to seasonal and interannual rainfall. Cash income is therefore important because food grown in areas with adequate rainfall can generally be purchased even if grain cannot be grown locally in some years.

Farmers fall into two categories of food purchasers: those who purchase by *volume*, who buy a greater quantity than the amount they sell, and those who purchase by *value*, who spend more money on food than they earn by selling. The common scenario is that prices to purchase grain in many West African rural markets is double in the summer at the peak of the growing season than it is post-harvest in the late fall. Take a household producing 110 percent of its caloric demand: if they sell 30 percent of their own-produced cereal post-harvest for cash income, they then need to buy back 20 percent of the total production in the summer (110% − 30% + 20% = 100%); due to price fluctuations, the household is a net buyer by value given a loss of 10 percent of total production (+30% − 2[20%]) = −10%). By having additional sources of cash income or understanding when prices are likely to rebound and delaying sale until that point, the household could avoid paying this penalty (Brown *et al.*, 2009). Information on the interaction of current growing conditions and likely impact of global food prices and typical seasonality could provide this information.

Millet in Mali, Burkina and Niger

Early analysis of the link between satellite remote sensing observations of vegetation in Mali, Niger and Burkina Faso and the seasonality of millet prices from 1982 through 2007 used a decomposition technique that allows the quantitative relationship of the seasonality of the environment to that seen in the food prices (Brown *et al.*, 2008). Brown *et al.* (2006, 2008) used monthly millet prices from 445 markets in Niger, Mali and Burkina Faso. The data were obtained from the early efforts of FEWS NET to gather and analyze food price (Chopak, 1999). The data have been kept in the local currency (CFA) and the series vary in length and begin in different years (Niger in 1982, Mali in 1987, Burkina Faso in 1989). Because these time series span the 1980s and 1990s as well as most of the 2000s, they provide historical perspective that data beginning after 2000 cannot (Brown *et al.*, 2006, 2008).

As was discussed in Chapter 3, remotely sensed vegetation data can be used to represent growing conditions for millet in West Africa in the two studies. Normalized difference vegetation index (NDVI) data have been used extensively in the Sahel to detect variations in vegetation production, and have been shown by a number of authors to be correlated to local crop yields (Fuller, 1998; Funk and Budde, 2009; Jarlan *et al.*, 2005; Vrieling *et al.*, 2011), and precipitation (Nicholson, 2005; Nicholson *et al.*, 1998). The AVHRR NDVI data has 8 km spatial and monthly temporal resolutions (Tucker *et al.*, 2005). The AVHRR sensor has appropriate spatial, spectral and temporal resolutions for West Africa (Becker-Reshef *et al.*, 2010; Justice *et al.*, 1991; Prince *et al.*, 1990). The mean of a five-by-five-pixel box (40 × 40 km) around on each market was calculated from monthly maximum value NDVI composites. This focus on only the immediate area around each market was a weakness of the analysis, since it is well known that many larger markets draw on farms for grain across a broad region, far larger than simply the area immediately next to a market (Aker *et al.*, 2010; FEWS NET 2009). This weakness is addressed in new analysis presented in Chapter 7.

West African production patterns

Like many semi-arid agricultural regions, the growing season in West Africa is monsoonal, with strong vegetative response to the rapid increase in soil moisture after the first few rains in June or July and lasting through September, with nearly all food grown during this period. A rapid increase in food availability occurs after the harvest in October to November. As the next growing season nears, food prices begin to rise as local food supplies fall and more households resort to purchasing food on the market. At the peak of the growing season, demand is high and supply is low, resulting in a growth in food prices, particularly in regions that are isolated. Plate 15 shows the time series for millet prices and vegetation from the three West

African countries from 1982 to 2007. The time series show significant interannual variability, as well seasonal dynamics.

Figure 6.2 shows all the data from Mali, Niger and Burkina from 1982–2007 averaged by month, showing the clear seasonality in both the food prices and in vegetation index. Changes in prices can be dramatic, in some years over 100 percent from the minimum prices. Coping with these significant changes is very challenging for many households.

The relationship between the seasonality of food prices seen in West Africa and environmental variability as observed by remote sensing has two primary aspects. These are the impact of the growing season and subsequent seasonality in food prices, and the impact of weather shocks on the price level in a particular year or series of years. These two aspects of food prices work together to affect food prices. The lower frequency trend is affected by the interannual variability of the weather, global food prices and the ability of the area to store grain as well as political and policy shocks. This trend is the component of the time series of food prices that varies over several years and affects the price level.

Weather shocks affect food prices also by directly affecting local incomes of rural households in multiple ways. Reduced production directly affects cash income from selling or trading own crop production, and through the need to replace self-grown household food through purchases on the market. Incomes are also affected through below average casual labor availability and reduced demand for services such as transportation, market services and other aspects of the informal economy that are important for local incomes (Camara, 2004;

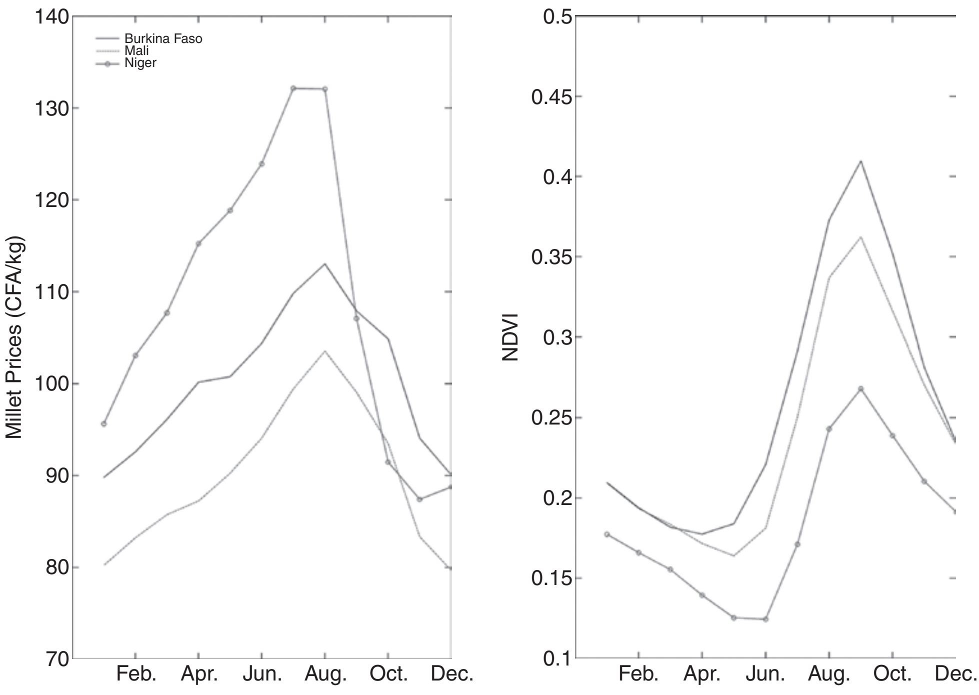

FIGURE 6.2 Averaged monthly millet prices (left) soar before the NDVI (right) peaks, data from Burkina Faso, Mali and Niger 1982–2007.

Venema and van Eijk, 2004). High staple food prices due to weather shocks affect food access through the combination of reduced income and reduced production. In a region where every year less food is produced per capita due to increasing numbers of people who need to be fed (Funk and Brown, 2009), changes in food prices and food production can result in reduced consumption and hunger unless adequate imports are obtained (Steffen *et al.*, 2012; Von Braun and Tadesse, 2012; Zant, 2013). This is particularly true of vulnerable individuals such as children, who will suffer long-term consequences if they reduce food consumption for a few months until prices come down.

Impact of climate variability

The conceptual diagram shown in Figure 6.3 shows the two pathways by which the weather affects food prices – through variations in production and through annual seasonality. Previous research has used decomposition techniques to identify and evaluate the interannual variability due to weather and other shocks and the seasonality of prices (Brown *et al.*, 2008; Cornia *et al.*, 2012). The connection between weather shocks and food price anomalies in West Africa continues to be a significant problem for food security in the region (Christensen, 2000).

The two aspects are linked since markets that have seasonality are particularly vulnerable to interannual variability of rainfall, since they are unable to cope with short-term declines in food availability during periods of higher demand, such as the height of the growing season. These same areas can be profoundly affected by production shocks, with high productivity in some years (leading to lower prices) and low productivity in other years (leading to higher prices). West Africa, particularly in the late 1980s and early 1990s when the millet dataset has the most observations, were not well integrated into the broader regional markets. This accentuated both the seasonality and the interannual variability of millet prices in the region.

The impact of both weather shocks and changes in supply/demand during the rainy season are mediated by storage, trade and transportation networks. The functioning of the local trade networks and the infrastructure available to commodity traders (storage facilities, inexpensive rail or trucking networks, low transaction costs) make all the difference in a market being highly affected by weather shocks and those that are not. Unfortunately, there is little or no information on local storage for grain, its cost and effectiveness in maintaining food preservation over different periods, for example. This lack of information on factors that mediate the connection between environmental shocks and food prices will increase the uncertainty of observed environment–price relationships.

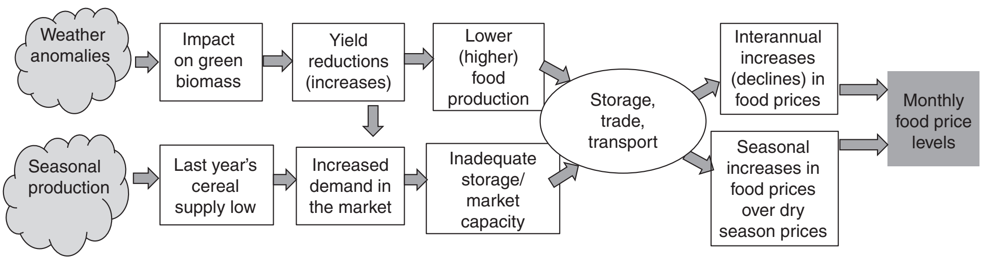

FIGURE 6.3 Conceptual diagram showing the impact of the interannual and seasonal weather effects on food prices in small and isolated market systems.

Table 6.1 shows the average price during poor, average and good years, as measured by remote sensing data. Although the table shows nice, neat differences in prices during different periods, the reality of food price data is far messier. Many things affect price levels, everything from elections and government policies about taxes and imports, to the amount of grain in storage from the previous year's crop, and what the rumors are about demand in different markets. Commodity price determination is very complicated, and given the number of years economists have spent working on developing effective models to forecast commodity price movements, many of the elements that determine prices are only marginally predicable (Baffes and Gardner, 2003; Deaton and Laroque, 1992; Tomek and Myers, 1993; Trostle *et al.*, 2011).

Figure 6.4 shows the same data used to create Table 6.1 in a histogram format for each country. The variability in actual observed prices in each year (good, average and poor) shows how difficult it is to demonstrate the impact of growing season variability on each country. The next chapter will discuss how each market needs to be treated individually, since grouping all markets according to which country they are in assumes a relationship between markets within a country that often works against understanding the dynamics between the environment where crops are grown and the market in which those crops are sold. Markets in Niger that trade more with Nigeria than with other cities in Niger, farmers who have long-standing relationships with traders in markets outside their immediate neighborhood or country, differences in storage capacity, wealth of the consumers and demand for particular product—all work against being able to use the country as the level of analysis.

Another factor complicating the relationship seen between NDVI anomaly and millet price dynamics analyzed here is the assumption that the vegetation index in a 25-mile area around each market is really the area of interest. The vegetation index used to determine the quality of the growing season in Figure 6.4 is the area around each market, not a broader region or based on any specific information that this area actually has grain to sell. Many agricultural regions produce excess grain and seek the market with the best price and adequate capacity to absorb the grain produced when it is available, even if it is not the nearest. The relationship between supplier and seller are undoubtedly as complex in Africa as anywhere – assuming that all farmers simply walk to the nearest market is an assumption that contributes to uncertainty (Figure 6.4). Thus expanding the geographic scope of the NDVI data integrated into this assessment is an essential next step in understanding the connection between poor growing conditions as measured by satellite data, reductions in yield and the impact of these changes on food prices.

TABLE 6.1 Millet prices in CFA/kg during August and September, using NDVI anomaly during the same period in Burkina, Mali and Niger over 1982–2007

NDVI anomaly	*Burkina Faso*	*Mali*	*Niger*
Below average	118.5707	107.1924	125.2000
Average	115.6478	99.5688	117.5255
Above average	101.0583	96.8137	112.9464

Note

NDVI anomalies are defined as above average and below average vegetation greenness during August and September, the peak growing season months, over the 25-year record.

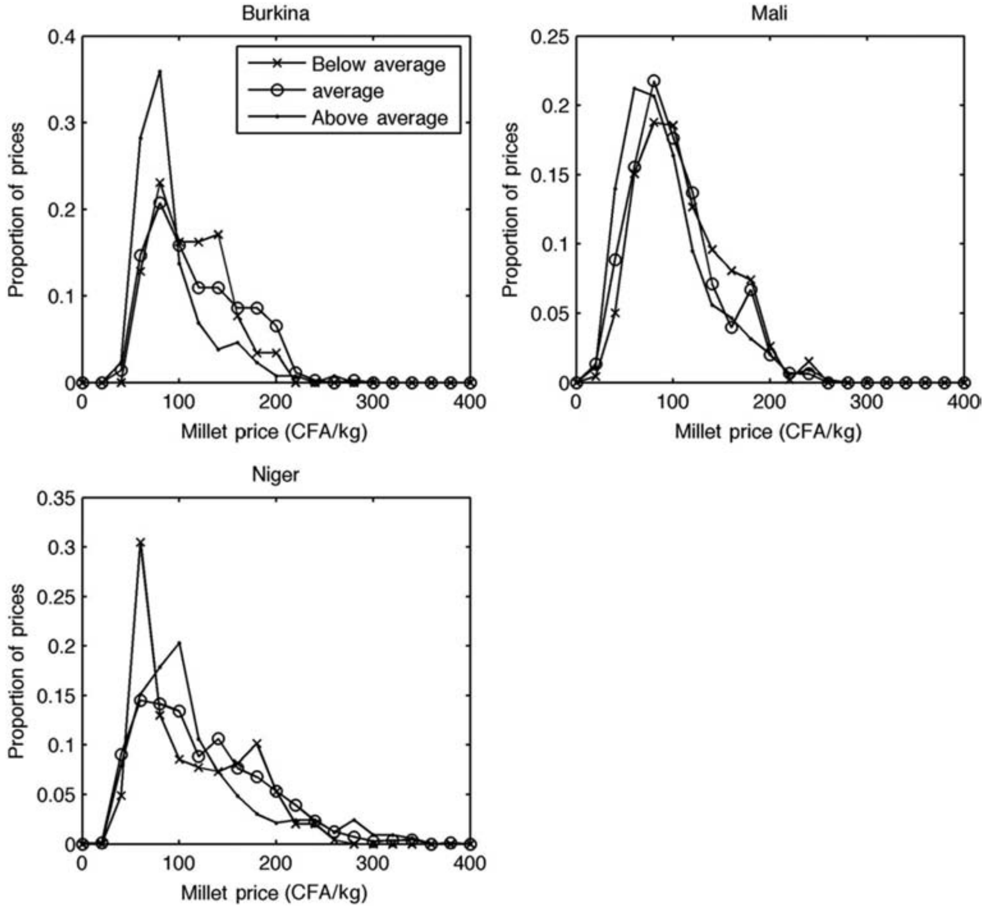

FIGURE 6.4 Distribution of millet prices in all markets during above average, average and below average growing years, as measured by vegetation index (source: data used are described in Brown *et al.*, 2008).

Seasonality in commodity markets across developing countries

Given the observed seasonality of food prices in places like West Africa, what can we say about the seasonality of food prices and the impact of local production on local prices? In regions outside the developed world, if local production is a significant factor, and the supply of food fairly limited, we would expect to see both interannual variability driven by weather shocks, and seasonality driven by cyclical changes in demand and supply (described in Figure 6.3). Areas that are dominated by the international commodity price should have very low seasonality in food prices.

Global seasonality for maize prices is shown in Plate 16. Here we show maize prices instead of millet or sorghum because maize is consumed in West Africa as well as many other regions around the world. Maize is one of the few global commodities that is grown and consumed across many different agroecosystems and cultures (Chapoto and Jayne, 2009;

Pingali and Heisey, 1999; Rojas, 2007; Wu and Guclu, 2013), and thus local market time series information is available for maize. The plate shows low, medium and high levels of seasonality for maize across all the developing countries in the world. India and China are excluded, since both these countries have effective price control programs instituted for commodity prices. Nearly all markets in Africa show medium or high seasonality for maize prices. More developed regions with better transportation networks and links to the international markets such as Mexico and countries in South America display low seasonality.

When these seasonal metrics are compared to the difference between the local and global maize prices for the period 2003–11, it is clear there is a relationship between the seasonality that a price time series exhibits and its isolation from the international market. Seasonal effects are more pronounced where markets are isolated. Plate 17 shows a correspondence between seasonal price effects and a country's isolation. Further, this correspondence continues to hold for locations within countries or sub-regions, such as West Africa or East Africa, and across commodities.

Impact of food price dynamics on household food consumption

Changes in food prices during times of scarcity of food result in a broad change in behavior by affected households (Devereux and Longhurst, 2009). These changes include:

- eating inferior foods;
- taking on extra wage labor;
- selling or bartering assets;
- rationing of consumption;
- postponing ceremonies or optional expenses;
- migrating to find work;
- borrowing cash or food; and
- cutting non-food spending.

During the hungry period, energy demands for farmers is high, since fields need to be cleared, planted and weeded, but little grain is left over from the previous year (Cekan, 1992; Glantz, 1990; Toulmin, 1986). The weather is hot and wet and roads are often even more difficult to navigate than usual due to mud and washouts. Women in particular have far less time and ability to travel to the market to seek the least expensive commodity, with the additional duties of helping in the fields added to their child care and food preparation duties. These changes confound the impact of increasing food prices and reduced supply, but are nevertheless important for understanding the impact of price seasonality on social welfare.

To understand how changes in food prices affect individuals and households, researchers set up studies that use interviews to elicit patterns of expenditure on food. Several studies in the nutrition literature focus on the impact on nutrition outcomes and food security due to changing food prices (Lavy *et al.*, 1996; Thomas *et al.*, 1992). Several studies are particularly interesting for the purposes of understanding price seasonality because they focus on the seasonal differences between consumption in the pre-harvest lean season when prices are high and the post-harvest dry season when food prices tend to be much lower, providing a case study of what happens when food prices rise without larger changes in the economic system (Becquey *et al.*, 2012; Hillbruner and Egan, 2008). Although the impact of seasonal price dynamics has long been studied in rural areas, this new literature shows that urban areas are also very sensitive to rapid changes in food price levels. Significant differences in food consumption during two periods were seen, attributable to the large change in the price of food from one season to the next (Becquey *et al.*, 2012).

There are strong linkages between food prices and nutritional outcomes (Lavy *et al.*, 1996; Thomas *et al.*, 1992), with income and overall food security affecting measures of long-term dietary inadequacy such as height-for-age. The proportion of the population living in urban areas is growing very quickly in the developing world, and particularly in the least developed countries in Africa. It is expected that the proportion of Africans living in urban areas will grow from 39 percent in 2000 to nearly 50 percent by 2020. While the population grows, the number of extremely poor households will also grow. These very poor communities are particularly sensitive to variations in food prices, since they often have little or no income and often rely on government safety nets or the broader community to survive.

In their nutritional survey, Becquey *et al.* (2012) had a large cluster sample of 3,017 households in Ouagadougou, Burkina Faso selected with a two-stage sampling design (Becquey and Martin-Prevel, 2008; Becquey *et al.*, 2010). The paper describes the sampled households during two rounds – first during the lean season, from June to mid-August 2007, which corresponds to the rainy season, and the second round took place during the post-harvest season, from November to mid-December 2007. The dietary data were collected on two non-consecutive days in each season by trained investigators who used a quantitative 24-hour recall method. For each household, the person in charge of household food preparation was asked to describe all food consumed in the household during the past 24 hours, and these foods were listed and qualitatively detailed for each eating occasion. The quantity of each food consumed in the household was then estimated using household measures, prices or standard portion sizes, taking leftovers into account. Also, for one of the two recalls for each season, individuals who were present in the household were asked to quantitatively describe all foods consumed outside the home. By sampling these two periods, the authors were able to capture the impact of changing food prices on household consumption (Becquey and Martin-Prevel, 2010). Household surveys are complicated and the details very important for the accuracy and applicability of the results. For more details on the survey methods and how foods were categorized, please see Becquey *et al.* (2012, 2010, 2008).

Household diets and seasonality

The results of the Becquey *et al.* (2012) analysis showed that the impact of higher food prices during the lean season was a reduction in the amount of food consumed in all but the most well-off households. Food security was negatively associated with food prices, economic dependence of adults and size of the household, with an overall reduction in the amount and quality of food served as prices rose. Education, the social network of the head of the household and the presence of family members originating from urban areas other than Ouagadougou were all positively associated with food security outcomes.

Another interesting outcome of the study is that in Ouagadougou, a large urban area, more households relied on ready-to-eat meals during the lean season. These consisted of rice with groundnut sauce purchased in the market and brought back to the home to be consumed. There were fewer fresh vegetables consumed during the lean season due to their price and overall availability. Although green leaves and onions were consistently available and inexpensive, other vegetables were 29 percent higher in cost during the lean season than in the post-harvest season. Other reasons for reduced number of meals prepared in the home during the lean season include:

- rain prevents women from traveling to the market;
- flooding of household, kitchen area, roads or market;
- immature and wet wood, the main fuel used for cooking; and
- lack of time to cook for those who practice urban agriculture (10 percent of the sample) (Becquey and Martin-Prevel, 2010).

Ouagadougou is not the only urban area to have documented the impact of food price seasonality on food consumption. Hillbruner and Egan (2008) document the ways that the weather and seasonal food prices affect household food security and children's nutritional status in Bangladesh. They showed consistently higher rates of malnutrition and food insecurity during the monsoon or lean season than in the dry season (Hillbruner and Egan, 2008). Changes in the rate of malnutrition outcomes in children were also seen in the Gambia (Teokul *et al.*, 1986; Tompkins *et al.*, 1986) and in urban Mozambique (Garrett and Ruel, 1999). In Bamako, Mali, it was shown that because of seasonal variations in food prices, families switched from one food commodity group to another to preserve the energy balance of the diet, to the detriment of the nutrient content of the meals (Camara, 2004). Many studies have focused on these effects in rural areas, but they are also prevalent in urban areas although not as pronounced (Lavy *et al.*, 1996). These studies cite food availability as well as the cost of food as being one of the drivers of increased malnutrition and food insecurity during the period, as well as increased disease and prevalence of disease vectors, and insanitary conditions due to the rainfall.

Summary

This chapter focused on documenting food price seasonality, focusing on research conducted in West Africa. Food price time series were presented and analysis provided that described how food prices are seasonal, the likely causes of the seasonality and the impact of interannual variability of growing conditions. A conceptual framework was presented that links price dynamics to weather and international food price changes. Research that has focused on the likely impact of food price variability on livelihoods and food security were described, along with the likely impact of changes in price levels over longer periods.

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7

MODELING THE IMPACT OF CLIMATE VARIABILITY ON LOCAL FOOD PRICES

Chapter objectives

This chapter presents research that seeks to explain the different impacts on local food prices of environmental seasonality, climate variability and variations in international prices. Demonstrating the impact of these three elements on local food prices with a model will help us put individual markets for different commodities into a typology, where variability from the international price and remotely sensed information are quantified. Some markets have prices that are not predictable using either international prices or environmental observations. This chapter will present the economic framework, model approach and results that allow for categorization of markets and countries into those affected by international prices, local weather shocks and both. The chapter ends with a brief discussion of the potential usefulness of an operational model that integrates weather and price shocks on local food access.

Food markets and shocks

To make the connections between climate variability and food prices that have been described in previous chapters into a functional tool that can used to improve identification of food insecurity, we need to develop a model that can use observations of climate variability during the growing season together with food prices. The model needs to be able to capture the impact of extreme events on prices, both where the event occurs locally and further away. Since weather events impact the amount of food that is available, markets are the mechanism for communities to access food from elsewhere to replace local shortages. Smallholders in remote areas face high costs, low producer prices with few buyers competing for their excess production and weak access to supporting services (Chamberlin and Jayne, 2013). When problems of access to markets are combined with problems of production, household food security can suffer.

Food prices are generally be the best short-term indicator of food availability as they reflect the actual market conditions and can be both easily observable and immediately analyzed, unlike observations of household food consumption or household income. Prices incorporate the expectations of traders, the volume of food in storage and any other unobservable factor that affects how markets function. When the prices in a single market are much higher than usual, an observer may ask if it is an artifact of the data, a reflection of unusual conditions in a single market and thus be an isolated incident or event, or reflective of a broader crisis emerging due to widespread problems of access. In order to answer these questions, a food security analyst must know how markets usually interact and their usual behavior at that time of the year. Understanding market price dynamics is an important part of food security analysis.

Markets are diverse, informal institutions that are complex, hierarchical and interlinked across space and time (Barrett and Santos, 2013). They function through complex relationships among many different individuals who work together to bring goods to a location for sale. This includes individual farmers, communities, public and private institutions and commercial traders who purchase food from farmers by visiting their farms in trucks, or may purchase the food grain from individuals at their farms or in smaller markets and then transport that grain to larger markets (Dorward *et al.*, 2004). When markets function well, the price of the same good between two nearby markets are highly correlated, with the difference between the two reflecting only transaction and transport costs that the traders incur (Ihle *et al.*, 2011; Minot, 2011; Jayne and Rashid, 2010).

The integration of prices in a market with those around it, and with the larger international market, depends on traders' ability to move goods into and out of the area, and the cost of these movements. In a competitive market, price integration is the outcome of an arbitrage process: trade between actors in different markets who aim to take advantage of price differences that exceed transaction costs (Lutz *et al.*, 1995). When prices in one market respond to a weather shock, but the prices in surrounding markets do not change, the market can be said to be isolated from the others. This lack of integration can be caused by a number of factors:

- Markets are isolated because transport systems are poorly functioning, because of public market protection, or for some other unknown reason.
- There are impediments to efficient trading, such as poor market information, risk aversion or trade barriers.
- There is imperfect competition because of collusion or preferential access to scarce resources (i.e., transport, credit) that may lead to higher price differences between markets than transport costs can justify (Lutz *et al.*, 1995).

Market integration is a way of diagnosing a problem with a market that may impact food security and access to food during times of crisis. Measuring market integration involves the analysis of the co-movement of prices through time, but it requires not just the price of goods in the two markets during the same period, but also specific temporal information on transaction costs and trade flows between the two locations. In developing countries this information is rare, usually only price information is used to estimate changes in integration. Co-movements cannot be separated from long-run trends and seasonality effects that are caused by factors not related to the level of integration between two markets, such as trends in food production due to climate, changes in energy costs and the cost of the good in the international commodity market (Goletti and Christina-Tsigas, 1995). Other factors that may affect integration are marketing infrastructure, government policy, differences in demand and dissimilarities in supply pathways to the market (Chamberlin and Jayne, 2013).

The behavior of each market in response to a shock is determined by a wide variety of factors that can be observed only with careful analysis and significant time to analyze the results (Masters *et al.*, 2013). Chamberlin and Jayne (2013) showed that expansion of trade networks was occurring throughout Kenya during the past decade that was only loosely related to physical infrastructure of roads and transportation routes. The penetration of private maize traders into even remote villages to purchase excess grain was far more extensive, but also more idiosyncratic and dependent on unobservable personal relationships, than previously observed. They also saw increased private grain assembly operations and investment in selling agricultural inputs in remote rural areas, which were uncorrelated to expansion in physical infrastructure. These changes are difficult to observe remotely, but can be inferred from food price analysis, especially if they change dramatically due to a severe external shock that restricts movement of traders or reduces excess tradable grain (Chamberlin and Jayne, 2013).

Incorporating information about the impact of climate variability on food production into models has the potential to significantly improve our understanding of the linkages between markets. A better understanding of the likely impact of weather shocks on markets can enable an improved response to isolated and poorly functioning markets. Differences in market behavior between those who have surpluses that can be marketed and those that do not, in commodity type, and in processing capabilities all tend to change market interactions (Goletti and Christina-Tsigas, 1995). Changes in growing conditions can impact an area's productive capacity to the point where a formerly surplus-producing region can become a deficit area, impacting trade flows and price differentials (Essam, 2013). Other kinds of supply shocks involve changes in road conditions (due to floods or other factors), the cost or availability of vehicle fuel, changing levels of policing on border crossings, and roadblocks set up by government or non-governmental organizations. Trade flows are dynamic and change as transportation costs fluctuate and demand for goods changes (Shepherd, 2012).

Role of trade in farmer behavior

As a country becomes less self-sufficient in food, its exposure to the international commodity market will require larger external payment imbalances (Moseley *et al.*, 2010). Requirements for imported grain increase as more farming households purchase food on the markets. Without modernization, domestic agriculture is unable to keep up with demand from urban areas. During times of drought the demand for grain increases throughout the country, including in rural areas that usually have a surplus (Masters *et al.*, 2013). There are also households who do not participate in the coarse grain market as sellers, as they have other sources of income (such as wage labor) that removes the need to sell food to the market (Zant, 2013).

Many households restrict their participation in the market because of high transaction costs (Shami, 2012). In remote markets poorly connected to other regions, farmers can experience high costs when trying to find trading opportunities. Barriers such as lack of transport, distance and/or differences in ethnicity or class reduce the ability of a household to know the selling price or the risks in the decision to bring their goods to market (Aker *et al.*, 2010; De Janvry *et al.*, 1991). Lack of participation by substantial portions of the population reduces supply and further increases the vulnerability of a market to climate variability (Egbetokun and Omonona, 2012; Goetz, 1992).

Households that do not participate in the market seek to be as far as possible self-sufficient in capital, labor and food to reduce exposure to variability in prices and extremely high transaction costs are both a cause and a consequence of thinly traded, volatile markets. Thinly traded markets keep the difference between produce and consumer prices high, further reinforcing households' incentives to minimize their reliance on markets (Tschirley and Weber, 1994; Kelly *et al.*, 1996).

Efforts to decrease transaction costs and improve market functioning and integration remain at the forefront of the effort in poverty alleviation and economic growth (USAID, 2012). A high degree of market integration implies a well-functioning market and smooth trade flows from areas of surplus to those of deficit, improved transmission of price signals, less price volatility and production decisions that are made according to information that is accurate (Zant, 2013). Market integration is also still regarded as central to issues of food security, since climatic hazards and local food production declines are becoming more likely in many food insecure semi-arid agricultural regions (Rojas *et al.*, 2011). Well-integrated markets for staple foods potentially offer a mechanism to reduce the impact of weather-related shocks, efficiently moving food from areas of surplus to those of deficit.

However, recent research has found that markets that are integrated and function well during normal or good years may be completely unable to function in poor production years. This can be due to the lack of supply of food and although there is demand in areas with poor supply, there may be a reduced capability by actors in the market to purchase food even when it is needed. Traders may avoid the cost of grain transport into these regions for fear of not finding enough buyers. Zant (2013) found that in Malawi,

> trade is seldom profitable, with prices similar and close to production costs in most districts in average and good years.... In periods of food shortage, districts are forced to trade with each other in an environment that lacks an adequate trading infrastructure for larger volumes, to make large outlays on transport, and to embark on uncommonly practiced and expensive district-to-district trade to remote rural areas.

In this context, food prices tend to become extremely high and access to food will become difficult. This potential for market collapse is a common reason for bringing in external food assistance from the humanitarian community. If the markets cannot supply food through normal channels then food availability can become a serious problem during a crisis.

Analysis can show how weather shocks affect food prices in a market or region. Previous work has used several different approaches to estimating the transmission of price shocks in markets, but there is no easy way to do so because of the lack of spatially and temporally explicit information often required by these analyses. Summarizing the rather large literature on spatial price transmission, Barrett (2008) offers a rather pessimistic perspective:

> Given limited data, in particular a paucity of data on transactions costs and trade volumes, and the intrinsic limitations of existing empirical methods, economists still have only a fragile empirical foundation for reaching clear, strong judgments about spatial market integration as a guide for corporate or government policy.

Given these challenges, a successful empirical technique linking weather shocks to food prices will need to work well in a small sample, be flexible and allow for temporary shocks and finally be able to explicitly model local price dynamics (Kshirsagar, 2012).

Modeling food price dynamics

To understand the impact of local weather and production shocks on food prices, models can be used that incorporate local food price time series, international price time series and regional NDVI time series data as inputs and generates local food price forecasts as outputs. Here, a price–NDVI model developed in collaboration with Varun Kshirsagar is presented that seeks to develop market-level predictions of commodity prices in food insecure markets using NDVI and the international price as its inputs. This model is an extension of previous work done by the author and her collaborators, but has a few novel elements, in particular the much more extensive use of satellite data from beyond the immediate area around the market (Brown *et al.*, 2009; Brown *et al.*, 2006; Brown *et al.*, 2008).

A successful prediction model will largely be a consequence of our ability to quantify and measure a major source of price variability – local weather shocks – whose influence on local food prices has not been previously quantified and analyzed in a systematic manner across a large set of countries. The approach presented here is novel in the following ways:

- pixels associated with NDVI signals are matched to locations from across a country's agricultural growing area, not just the local area around a market;
- seasonal price changes are modeled jointly with the effect of NDVI anomalies; and
- generation of out-of-sample price forecasts that can guide food security analysis.

If implemented in near-real time using current remote sensing and the latest price information, the model can be used to understand the impact of large droughts on surrounding markets through empirically connecting food price changes with vegetation signals. This approach can also be used to understand seasonal variation in local food prices, and provide an assessment of the vulnerability of these places to environmental change and to global commodity price changes. The work can provide a predictive element to early warning organizations' efforts to monitor food prices, and can add an analytical component to the necessarily qualitative analysis of the impact of drought on livelihoods in specific markets. There is usually a delay of a month or more between the time of the commodity price observation in a market and when it is incorporated into a database for access. Thus projections provide information about current food prices, and can be integrated into food security outlooks, which are focused on providing assessments of the food security situation in the coming three to six months.

Although true price "predictions" have limited use and present a thorny problem for organizations such as the US government funded FEWS NET whose influence in the region is extensive, projections that capture the likely future dynamics of prices could be of great use to humanitarian organizations. To capture a significant change in direction, from increasing to decreasing prices across an area for example, due to external influences from the weather or of production that cannot be observed either locally or from afar, would be of great use. In addition, if a model can estimate which markets and which commodities are likely to be affected by an observed weather anomaly, then a much more accurate analysis of the livelihood impacts of the event can be conducted. The objective of this model is to quantitatively assess the impact of spatially extensive weather anomalies on specific markets in a way that can be replicated, and can be regularly provided to decision makers.

Food price analysis demonstrates the influence of local weather shocks on local food price dynamics across a large set of developing countries on four continents. The results suggest that local grain markets in Sub-Saharan Africa are largely unaffected by world grain prices while rice markets are typically affected by changes in world rice prices, a result also supported by Brown *et al.* (2012). Using a model that incorporates NDVI as one of its drivers was able to show that 87 out of the 179 locations were influenced by local weather anomalies during the 2003–12 period. It is likely that these areas would benefit the most from interventions that strengthen the food supply chain and the resulting improvements may help mitigate the uncertainty arising from weather anomalies (Kshirsagar, 2012).

Price–NDVI model conceptual framework

In a market with functioning information flows, efficient storage and transport infrastructure, food price changes from one month to the next will mainly reflect differences in the cost of transport and other transaction costs. As described by Hayek (1948), market prices will adjust through a dynamic process. Traders and intermediaries would anticipate both a shortfall in the food deficit location and the resulting increase in local prices. Consequently, they will choose to buy more from the surplus region and sell more at the deficit location until their profit from the extra food sold has been maximized, or the demand satisfied. Therefore, a local weather shock may exert a temporary influence on local price in a chronic food deficit market, but in equilibrium price differences will reflect differences in transport costs because traders will move goods to take advantage of the increase in prices in a market. As a result, local food prices in food deficit regions will be determined by world prices if the country trades with the others in the world market, producer prices, tariffs and other market costs, and transport costs (Hayek, 1948).

How might this mechanism fail? There are at several factors that might cause the price forming mechanisms to diverge from the Hayekian version of "perfect" markets. First, and perhaps most importantly, ad hoc government policies introduce a great deal of uncertainty in the expected returns for traders. As Tschirley and Jayne (2010) have argued, this factor was responsible for Southern Africa's major food crisis in 2008–09. Second, credit constraints, and credit market imperfections more generally, impede the ability of traders to exhaust arbitrage opportunities (Kshirsagar, 2012).

Aker *et al.* (2010) showed that ethnic differences in West Africa are responsible for sub-national market imperfections and argued that this is partly driven by inter-ethnic trading frictions. The larger the changes in the quantity and geographic scope of possible trading opportunities, the more important credit constraints become for traders working in these markets. Traders cannot access sufficient amount of goods due to lack of credit to make moving goods from one market to another profitable, particularly when moving between regions with different ethnic composition.

Weather-related production volumes also make a big difference in the ability of traders to move goods profitably. Zant (2013) showed that maize markets in Malawi functioned very differently during periods of average or above average production than during times of below-average production due to constraints in the ability of traders to move goods. Variations in production can transform a region from a food surplus to a food deficit region, entirely changing the trade direction. Because transaction costs represent a dominant component of market prices, especially in the case of low value, high volume staple food with low production costs such as manioc, millet or yams, incomplete or missing transportation or transaction costs will greatly change a price analysis and lead to inaccurate conclusions (McNew and Fackler, 1997; Baulch, 1997). In developing countries, lack of complete data on trading or transportation costs is the rule, rather than the exception. Crime and/or civil conflict could also raise trading costs to a prohibitive level (Turner, 1999).

Figure 7.1 captures the essential elements of local food price formation in food deficit areas. In equilibrium, on average, local food prices are not determined by local food supply shocks, but rather by changes in the price at which local consumers can buy food imported from elsewhere. Changes in this "import parity price" are largely determined by changes in transport costs including changes in crime, civil unrest and fuel prices, food aid, ad hoc government policies, world prices if the local market is connected and/or supply shocks to the national or sub-national food surplus areas.

Will a positive supply shock (e.g., favorable rainfall) in a food surplus location influence local prices? No food supplier is going to choose to supply goods at a price lower than the cost of goods purchased elsewhere. Consequently, this export parity price represents a price floor. However, particularly for isolated markets, the export parity price could be quite low. In these markets, local supply shocks will influence local prices. The extent of the influence depends, in part, on trade costs. Figure 7.2 shows the elements of local food price formation in isolated food surplus areas. The influence of a given weather shock on local prices will depend on the magnitude of the shift in the local supply curve, but also on the relative elasticities of local demand and supply. If supply is completely inelastic, prices will fall sharply when the location receives favorable weather. This is particularly true in regions where most farmers grow the same crop and have limited ability to move their goods beyond the local market. The ability to store grains during large harvests will help mitigate the adverse consequences of large local surpluses (Shepherd, 2012; Jones *et al.*, 2011).

Figure 7.3 captures the essential elements of local food price formation in a food surplus area connected to urban areas with efficient transportation networks. While shocks to local supply do exert an influence on local prices, the magnitude of this influence will be small and will depend on locally determined trade costs. For these markets, increases in world food prices and domestic fuel prices have opposing effects on local prices. An increase in world food prices raises the export parity price, while an increase in domestic fuel prices lowers the export parity price. The net effect will depend on the distance to a major market, and the availability and quality of infrastructure.

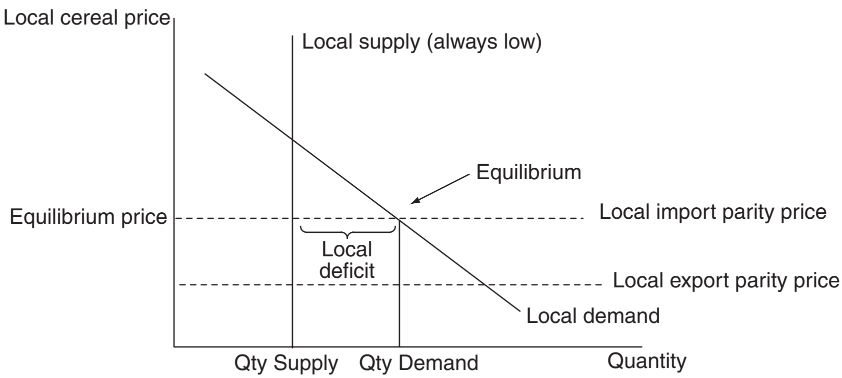

FIGURE 7.1 Local supply shocks do not determine equilibrium of local prices in a food deficit market (inelastic supply curve) (source: Kshirsagar, 2012).

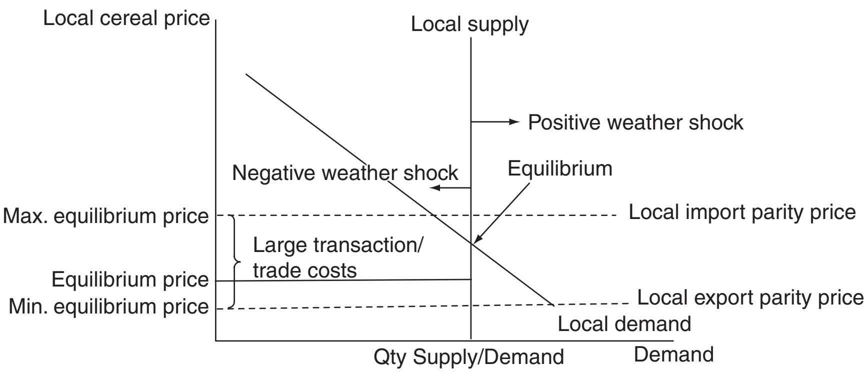

FIGURE 7.2 Local supply shocks determine equilibrium local prices in an isolated food surplus market (source: Kshirsagar, 2012).

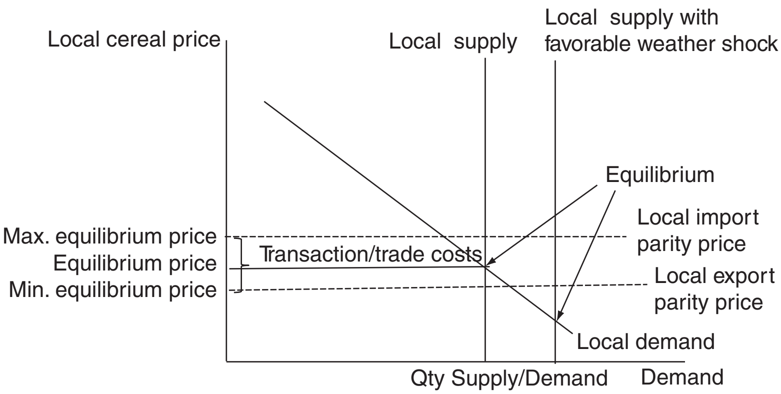

FIGURE 7.3 Local supply shocks partially determine equilibrium local prices in a connected food surplus market (source: Kshirsagar, 2012).

For a chronically food deficit location, we would not expect to observe a significant relationship between local weather shocks and local food prices. World prices may influence local prices in this area, but this will depend on, among other factors, transport costs, government policies and whether markets are functioning properly.

Basic economic reasoning can provide guidance in linking a location's characteristics to the likelihood of it being affected by local weather and/or world price shocks. Given the variety of factors that are likely to influence market functioning, considerable heterogeneity among locations is likely, even within a country and perhaps within an agro-ecological zone, regarding the influence weather and external shocks have on local price formation.

The model uses both international food prices and spatially explicit information on weather shocks to study food market functioning to provide useful guidance regarding areas that are most likely to benefit from marketing/supply chain interventions or food aid. The model assesses how climate variability is likely to affect food market prices and functioning, and how international prices will reduce or exacerbate these impacts.

Data

Food price data used in this model are sourced from the UN FAO food price tool and from the FEWS NET food price database, include data from rice, wheat, maize, millet and sorghum, and are from 124 locations in 36 countries. The prices are from the FAO food price tool (www.fao.org/giews/pricetool/) and from FEWS NET and its member countries. The series used here are only from 2008–12 to remove incomplete and missing months, and to have as comparable series as possible across as many locations as possible. A map of the locations where the series are from is provided in Plate 1.

The vegetation index data used in the analysis are the monthly NASA Moderate resolution Imaging Spectroradiometer (MODIS) Aqua NDVI from 2003 to 2013 (Huete *et al.*, 2002). The data used are the MODIS Climate Model Grid monthly dataset at 0.05-degree resolution. More information on the NDVI product and the data from MODIS sensors more broadly can be found in Huete *et al.* (2002). These data are used to derive temporal monthly anomalies by pixel that quantified the impact of drought, or unusually low rainfall or moisture conditions due to high temperatures. All vegetation data have uncertainties from cloud contamination, dust and other aerosols in the atmosphere, unusual soil moisture conditions, or other phenomenon that may not be related to actual vegetation health, thus we did not consider anomalies of less than 10 percent. To remove the influence of non-agriculture areas from the analysis, we used the NASA MODIS land cover map to identify areas that were forest, water, desert or urban and masked these pixels (Friedl *et al.*, 2002).

Empirical methodology

The model presented here uses a state space approach to mathematically model local price dynamics, which was popularized in the economics literature by Harvey (1989). This approach has the following advantages:

- it works well in a small sample (Harvey, 1989) and uses a time—series approach which can easily incorporate information from the remote sensing data (Shumway and Stoffer, 2010);
- it explicitly models price dynamics, important for the the early warning community;
- because it models the autoregressive nature of prices, it does not assume stationarity (Harvey 1989);
- prediction one or several months ahead follows naturally because the estimation procedure models a dynamic process using a Kalman filter; and
- by decomposing a price series into trend, seasonal and trend components, it allows the analyst to interpret better noisy time series and relate them to environmental dynamics (Brown *et al.*, 2008, Cornia *et al.*, 2012).

By partitioning the data into components that have variations at the same time scale as the growing season, the seasonal component that is most related to crop production could be isolated. Figure 7.4 shows a price time series from Nairobi, Kenya and the three

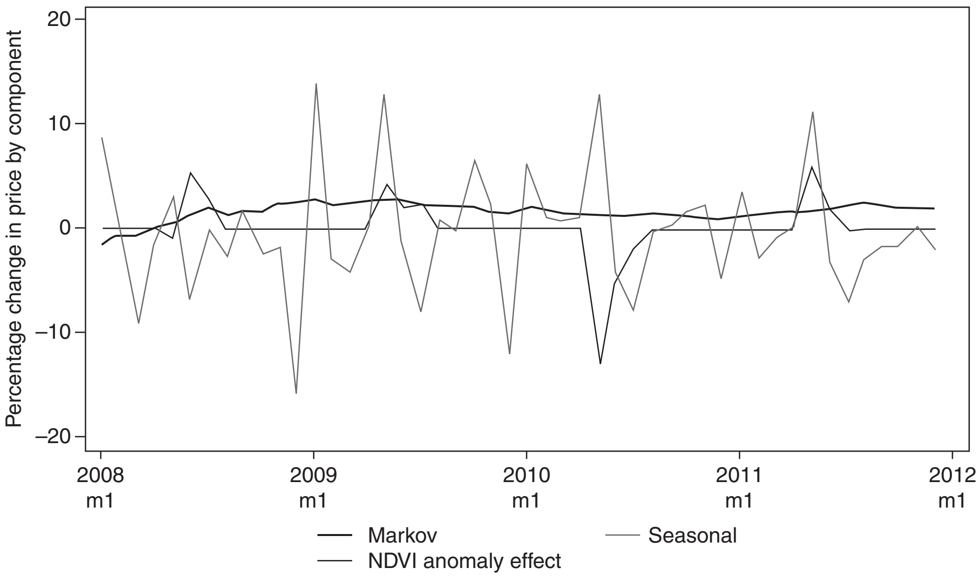

FIGURE 7.4 Seasonal and Markov price components and NDVI anomaly for Nairobi, Kenya.

components used in this study. The Markov trend and seasonal components are linked with the NDVI anomaly information to capture the information in the weather shock with the analysis.

By using satellite-derived vegetation data to account for seasonal variations as well as estimates of drought on changes in price levels (Deaton and Laroque, 1992; Brown *et al.*, 2008), we estimate local price dynamics by incorporating seasonality (using monthly dummies), an autoregressive process and a trend (where applicable). We also incorporate explanatory variables as shocks to this system (Harvey, 1989). The autoregressive process has a time varying error. We estimate the impact of two explanatory variables – world prices for the relevant commodity and normalized difference vegetation index anomalies. These anomalies are calculated only for those months for which the ten-year monthly average is at least half as large as the average of the highest month. This allows us to restrict possible impacts to anomalies in months that are likely to influence local food prices. We use three month lags for each and the total impact for each factor is evaluated by summing up the coefficients.

By explicitly measuring weather anomalies and world price changes as shocks to a dynamic system, we reduce the possibility that price changes coincidentally move with external shocks. For example, by explicitly modeling seasonality, we are eliminating the possibility that estimated impact of a world price increase merely reflects coincidental seasonal movements (Figure 7.5).

A weakness we share with other approaches is our inability to measure transport costs. We could either assume stationary and proportional transport costs or ignore them. We chose the latter because it is clear that transport costs are not stationary for the countries that we examined. In future work, we would like to measure transport costs using additional data on distance and local fuel prices, and incorporate transport costs and the attendant non-linearity into the estimation methodology.

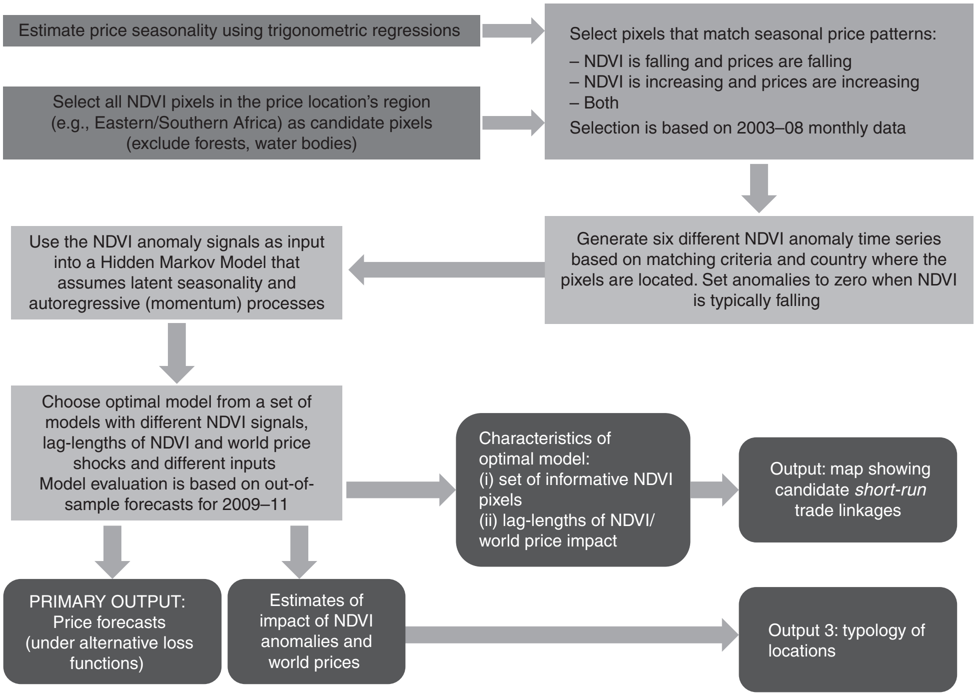

FIGURE 7.5 Summary of methods for price–NDVI model.

The model then uses the seasonality of food prices together with NDVI to estimate which NDVI time series is most related to food price variation for a particular model. The NDVI pixels from agriculture regions in a country are averaged and used to create anomalies, which can capture weather shocks on food prices. Then the model assumes seasonality and auto-regressive momentum processes. Next, multiple models are developed with different NDVI signals, lag-lengths and inputs and the algorithm chooses the optimal model from a set using regression statistics. The optimal model is the one with the best out-of-sample performance over three years (2009–11). The optimal model in one location could differ from the optimal model in another location based on several criteria:

- Relevant pixels could be exclusively inside one country or also in other countries in the region. The pixels could be close or farther away from the location depending on market size and trade dynamics.
- The optimal model could potentially include world prices as an explanatory variable or it may not.
- NDVI anomalies and world prices could have different lag-lengths.
- Persistence of moisture deficits and price momentum from previous years could be incorporated into current year estimates.

Such a model would provide additional information about the location and the relationship between price dynamics and weather shocks that is currently not available. The model then has several outputs, including price forecasts during the 2009–11 period and maps of which NDVI pixels are related to observed price changes.

Maps of NDVI time series correlated with price changes

When using NDVI time series to estimate changes in food prices, the question arises, where should the NDVI be from? Each market can draw from a variety of export locations, which may change dynamically after each harvest. As some regions have excess grain and have relationships with traders, some connections may be static and others may be active depending on the region and the year's production. Here we present maps that show the relationship between the price seasonality and NDVI anomalies, to demonstrate the areas that are more related to changes in food prices for a particular commodity and market. We can then make maps of the NDVI pixels that are most correlated to the local food prices. Although this does not give us exact information about where food may be coming from, it is a big improvement over using only the NDVI around each market. In some regions, such as East and Southern Africa, there are significant movements of grain in cross-border trade.

Plate 18 shows the pixels in Western Africa most related to maize prices in Njamena, Chad during the 2003–08 periods. The plate shows a clustered band of pixels along the Sudanian region that are approximately regions that have NDVI most related to the seasonality of maize prices in Njamena. Since NDVI in the region is highly correlated to rainfall, and rainfall is likely to be similar across latitudinal bands (Nicholson *et al.*, 1998), the horizontal band of pixels is to be expected. Thus the pixels shown in Plate 18 are all highly correlated with each other and with the growing conditions seen in the export zone.

Plate 19 shows FEWS NET's Markets and Trade Flow Map for Chad. The map provides a summary of experience-based knowledge of market networks significant to food security. Maps are produced by USGS in collaboration with other FEWS NET staff, local government ministries, market information systems, NGOs, and network and private sector partners. The maps are the result of interviews with experts and local traders, and are meant to represent normal trading patterns during a normal year. They are also static in time and do not show seasonal impacts of trade or specific annual differences. Because food price spikes often occur in years that are not average or normal, these flows are not very useful to assess the impact of extreme events. These maps are also not available digitally, so they cannot be easily quantified and used in a model, as they are meant only as a guide to how trade usually moves. These characteristics reduce the maps' utility for model development, but their usefulness for comparison to the quantitatively assessed maps remains.

The pixels highlighted in the Njamena maize map roughly match up with the location of the Bol export zone, but are much more widespread across the area. This may occur because of the similarity in the NDVI signal between the pixels in the Bol zone and the other areas surrounding the country. On the other hand, since the FEWS NET map does not include areas outside Chad, thus it may be that maize is transported from these other regions into Njamena.

Plate 20 shows the pixels related to maize prices in Nampula, Mozambique are far more widespread than those identified for Njamena. Mozambique has a much more developed regional trade network as well as a larger maize export zone which takes up nearly the whole country, as seen in the trade flow map from FEWS NET (Plate 21). The source locations for Nampula thus are quite extensive, with pixels highlighted both north and south of the market, as well as from surrounding regions outside Mozambique. For this particular analysis, Zimbabwe was excluded, which is why there are no pixels represented from the country. The locations with related NDVI pixels include a dense cluster south of Lake Cahora Bassa, which the FEWS NET map describes as a minor deficit zone, regions in the south of the country in Chokwe, and regions in the north in Tanzania near the Rift Valley lakes. These maps of active NDVI pixels, once included within the framework of FEWS NET, can become useful for understanding how trade flows change during times of deficits in rainfall and food production.

Comparison of model predictions

To demonstrate that a country's NDVI anomaly over agriculture regions is really useful in the model for improving price predictions in key markets, we compare predictions using models specified using 2003–08 local maize prices, and evaluated the results using price data during the 2009–12 period. Although the model has been implemented on all data, in Table 7.1 we present the results of maize and millet price predictions from 42 markets in 11 food insecure countries in Africa. In this analysis, a "naïve" model, comprising only previous-month (or Markov)-based price forecasts, is compared to three other models:

- previous month or Markov price analysis alone;
- previous month and seasonality;
- previous month, seasonality and NDVI estimates;
- previous month, seasonality, NDVI and world prices.

As we add more parameters to the model, we expect to capture more variability in the price dynamics and thus have a lower percent error in markets where these elements are important. Table 7.1 has highlighted in grey the lowest root mean square percent error compared to the actual prices during the 2009–12 period, which shows the model that is best able to capture the observed variability of the prices in the market (Kshirsagar 2013).

In seven of the 42 markets the Markov-based predictions alone are best able to capture price dynamics and have the lowest error as measured by RMSE. In 21 markets, the Markov model and information on seasonality model is able to improve the forecast. In some markets, this improvement is only marginal but in others the root mean square percent error (RMSPE) between the predicted and observed prices declines by 2 to 4 percent. As discussed in Chapter 6, seasonality is a critical element of not only local food production but also of food prices in many regions where food security is a problem and the local markets do not function well. Thus the impact of including a seasonal component to a Markov model demonstrated in this analysis shows the importance of including information on seasonality in price modeling approaches.

When adding information on NDVI, the price prediction is improved in four markets – Mbeye and Arusha in Tanzania, Garissa in Kenya and in N'Jamena Chad. These locations are isolated from the world markets and from regional trading centers where the world market prices are influential. When the NDVI and the world market prices are included together, a further improvement in the prediction of prices in ten additional markets is seen. Some of these predictions are significant improvements over the naïve Markov model, reducing the errors from 24 to 16 percent error.

The standard set in this assessment is very strict, since in a model focused on providing actual predictions in an operational framework, we would not train the model with prices that are out of sample, or from different years from the years in which the prices are being predicted. The results provide insight into the critical interaction between global prices and growing conditions in the region where a market obtains its food grains. The local growing conditions and the ability of traders to access additional grain from the international market interact to affect local food prices. Thus when determining the impact of local growing seasons on food prices, consideration of the international price of a comparable grain is important. Particularly in regions where information on the availability and cost of transportation and the local connections with the international market are unknown, this insight is important (Kshirsagar 2012).

Local market response to shocks

The modeling framework presented above will allow analysts to categorize markets with regard to the likely impact of droughts and other weather shocks on food prices. Some markets have more food that is sourced locally than others, and every market has different transportation and transaction costs that are difficult to quantify from afar. These characterizations are important for the kind of qualitative assessments of the impact of food price variability on food security that are routinely done by FEWS NET and other organizations that monitor food security. Local weather events, even those that do not actually result in production declines, can have an impact on food prices locally. The lack of data on specific market-level factors such as trade volumes, informal transactions costs and other unobserved, time-varying market heterogeneity significantly reduces the ability of food security analysts to assess what these impacts are or the likely future change of food prices due to a shock. Thus using the observable weather information along with global food prices in a quantitative model can improve an organization's ability to estimate food price changes in regions where food security is a concern.

What impact do weather shocks have on any one country or region? To explore this issue, we will return to our example in Niger, where there are many markets with food price observations over three decades. A study by Essam (2013) showed that millet markets in Niger in zones with excess millet production tend to generate leading price signals to periphery markets located in less intensive production zones. However, the temporal nature of these relationships is varied and recent trends suggest that there have been improvements in overall market integration in Niger. A correlation analysis conducted by Essam shows that in years following weather-related production shocks, market prices tend to move more closely in tandem than in years of abundant production. It is only through an analysis of the spatial relationships between markets that permit such a conclusion, although analyzing connection between markets is very difficult without significant information on trading networks and transaction costs that are rarely available in real time (Essam, 2013).

To further investigate this latter conclusion, Essam estimated a price dispersion model that analyzes the effect of exogenous weather shocks as measured by NDVI on price spreads between markets. This price dispersion modeling results suggest that negative (positive) NDVI shocks decrease (increase) price dispersion. As the extent of an NDVI shock grows, captured by the percent of markets with a negative NDVI shock, absolute price dispersion declines between six and ten CFA per kilogram of millet (Essam, 2013). These results are robust across both standard fixed-effects models and specifications that include a dynamic adjustment factor, with adjustments made to the standard errors to account for general forms of cross-sectional and temporal dependence.

TABLE 7.1 Results from the price-NDVI model for maize. Highlighted RMSPE indicates the lowest error and best fit model.

Price series			*Markov forecast*	*Markov + Seasonal*	*Markov + Seasons + NDVI*			*Markov + Seasons + World price + NDVI*[6]				
Country	*Location*	*Commodity*	*RMSPE*[1]	*RMSPE*	*RMSPE*	*ndvi_p*[2]	*ndvi*[3]	*RMSPE*	*ndvi _p*	*ndvi*	*wprice_p*[4]	*Worldprice*[5]
Benin	Cotonou	Maize	18.2	18.4	–	–	–	–	–	–	–	–
Senegal	Ziguichor	Maize	14.9	13.4	–	–	–	–	–	–	–	–
Ghana	Tamale	Maize	20.4	14.9	–	–	–	–	–	–	–	–
Niger	Diffa	Maize	11.1	10.0	9.4	0.00	–0.88	9.1	0.00	–0.97	0.27	0.22
Niger	Gaya	Maize	20.4	15.0	–	–	–	–	–	–	–	–
Niger	Maradi	Maize	11.4	8.2	–	–	–	–	–	–	–	–
Niger	Niamey	Maize	8.0	–	–	–	–	–	–	–	–	–
Niger	Tounfafi	Maize	12.2	8.6	–	–	–	–	–	–	–	–
Niger	Agadez	Millet	9.7	8.7	7.7	0.01	–0.68	7.7	0.01	–0.63	0.28	–0.16
Niger	Diffa	Millet	13.5	13.1	12.4	0.02	–0.69	11.9	0.01	–0.77	0.39	0.16
Niger	Maradi	Millet	12.6	10.9	–	–	–	–	–	–	–	–
Niger	Niamey	Millet	7.8	6.9	6.5	0.01	–0.62	6.4	0.01	–0.56	0.16	–0.21
Niger	Tahoua	Millet	16.0	12.7	–	–	–	13.1	0.11	–0.50	0.37	0.19
Nigeria	Kano	Maize	16.2	15.0	–	–	–	–	–	–	–	–
Nigeria	Kano	Millet	19.8	18.6	–	–	–	–	–	–	–	–
Chad	Abeche	Pearl millet[7]	13.5	14.9	11.7	0.02	–0.95	11.6	0.02	–0.85	0.35	–0.21
Chad	Moundou	Pearl millet	11.1	11.8	–	–	–	–	–	–	–	–
Chad	Moussoro	Pearl millet	10.8	11.9	–	–	–	10.5	0.15	–0.49	0.73	0.07
Chad	N'Djamena	Pearl millet	12.4	14.5	14.1	0.11	–0.56	14.1	0.06	–0.66	0.37	0.19
Chad	Sarh	Pearl millet	13.7	12.2	–	–	–	–	–	–	–	–
Chad	Bol	Maize	18.6	16.2	–	–	–	–	–	–	–	–
Chad	Moussoro	Maize	14.6	12.8	–	–	–	–	–	–	–	–
Chad	N'Djamena	Maize	13.7	12.9	12.8	0.10	–0.46	12.9	0.07	–0.51	0.82	–0.05
Kenya	Eldoret	Maize	13.4	16.8	–	0.07	–	15.54	0.07	–0.45	0.89	0.03
Kenya	Mombasa	Maize	12.4	13.4	–	–	–	–	–	–	–	–

Kenya	Nairobi	Maize	13.7	13.9	–	0.04	–	13.5	0.04	–0.33	0.83	–0.04
Kenya	Garissa	Maize	21.2	22.3	19.4	0.04	–1.01	–	–	–	–	–
Malawi	Bangula	Maize	18.6	18.0	–	0.10	–	17.3	0.10	–0.80	0.77	–0.08
Mozambique	Chokwe	Maize (white)	22.9	22.2	–	–	–	–	–	–	–	–
Mozambique	Angonia	Maize (white)	22.5	19.5	–	–	–	–	–	–	–	–
Mozambique	Gorongosa	Maize (white)	25.7	25.6	–	–	–	–	–	–	–	–
Mozambique	Manica	Maize (white)	17.6	13.8	–	–	–	–	–	–	–	–
Mozambique	Maputo	Maize (white)	12.9	13.3	–	–	–	–	–	–	–	–
Mozambique	Maxixe	Maize (white)	15.3	15.8	–	0.08	–	14.3	0.08	–1.09	0.64	0.12
Mozambique	Nampula	Maize (white)	17.3	15.7	–	–	–	–	–	–	–	–
Mozambique	Nampula	Maize (white)	17.4	14.5	–	–	–	–	–	–	–	–
Mozambique	Ribaue	Maize (white)	23.8	19.3	–	–	–	–	–	–	–	–
Rwanda	Kigali	Maize	21.0	20.1	–	–	–	–	–	–	–	–
Tanzania	Arusha	Maize	16.6	11.9	11.7	0.02	–4.09	–	–	–	–	–
Tanzania	Dar es Salaam	Maize	11.8	11.0	–	–	–	–	–	–	–	–
Tanzania	Mbeya	Maize	11.9	–	9.8	0.09	–4.36	–	–	–	–	–
Tanzania	Songea	Maize	24.3	18.7	16.5	0.01	–1.34	16.4	0.01	–1.57	0.85	–0.06

Notes
1. Root mean square percent error between predicted 2009–12 prices and actual prices.
2. P value of NDVI in model.
3. Coefficient for NDVI in model.
4. P value of world prices in model.
5. Coefficient for world prices in model.
6. Results for each model are reported when input elements have a significant *p* value, even if RMSPE is higher than the naïve model target.
7. For millet, we used maize international prices for the "world price" in the model.

Econometric analysis of historical price data from the region over three decades suggests that positive NDVI is associated with markets that appear to be less integrated, as evidenced by the decreasing effect of neighboring price lags in a good year on a markets observed price. Essam conducted an analysis, using model fit criteria that shows that by including specific regime variables that interact with lagged price bands from neighboring markets, we can improve the overall fit of our base cereal market performance model. The regime variables are based on NDVI anomalies that provide the overall abundance of millet in the region, providing information that was previously not available to the model.

Essam also uses probability modeling to assess the ability of NDVI anomalies to predict future price regimes for inclusion in his millet price prediction model. The results suggest that NDVI anomalies from May, June and July have a rather limited ability to predict accurately future price regimes. However, as he included additional NDVI anomalies from previous months (March and April) that capture weather conditions and the amount of senesced vegetation on the ground before the start of the growing season, his ability to predict price regimes increased dramatically. This may be due to the importance of the previous year's moisture conditions on the current year's food stocks. NDVI can show variation in biomass in crop residue and other senesced vegetation, as well as differences in soil moisture over large areas (McNally *et al.*, 2013).

The model also showed that in bad years, on average, markets appear to be better integrated and in good years, on average, markets are less integrated, where integration is measured as the degree of price transmission from neighboring markets. Market integration is an important metric for estimating the impact of local weather shocks as well as international price signals on local food security (Essam, 2013). Market characteristics can be inferred from their response to different shocks.

Impact of weather and global food price shocks

The behavior of local markets assessed in the model described above has different characteristics that can be summarized in a general typology, presented in Table 7.2. The typology provides an explanatory matrix to describe why we see differences in the impact of weather and international price shocks on different markets. The typology is a useful way to think about why each market is affected by these shocks and how these impacts are likely to change over time. It is not meant to capture all the different sources of variability but to simplify complex relationships so that they can be examined more easily. It is unlikely that these relationships will stay the same during periods of extreme stress, such as during very high international prices or very low food production due to weather shocks, but categorizing how markets are affected will help information about these shocks be more easily used. Econometric models that use NDVI as one of the input parameters, such as the study conducted by Essam described above, will allow further exploration of these issues as the length of the price time series as well as the locations that have price data expands.

Market-commodity pairs not affected by either international price or weather shocks

In countries that actively control food prices, we expect to see shocks have less of an effect on local prices. Kenya, Malawi, Zambia and Zimbabwe can be classified high-intervention

TABLE 7.2 A typology of local cereal markets: market structure and price behavior

	Local weather shocks have no effect	*Local weather shocks influence prices*
Global price shocks *have no effect*	• Low cereal stock–use ratio • Food deficit areas/connected to food deficit areas • Weather shocks in other food surplus areas affect local prices • Low-income countries • Includes markets in Ghana, South Africa, Sri Lanka, Sudan, Tanzania	• Isolated/landlocked country • Poor, rural, inadequate infrastructure • Food surplus area that trades with larger food surplus area • Low-income countries • Includes markets in Bangladesh, Burundi, Chad, India, Kenya, Mali, Mozambique, Nepal, Niger, Pakistan, Panama, Senegal, Somalia, Thailand, Togo, Uganda, Zambia
Global price shocks *influence prices*	• Food deficit area or food importing country • Connected location/non-landlocked • Food deficit region in more advanced developing country • Urban/capital location • Includes markets in Afghanistan, Benin, Burkina Faso, Burundi, Guatemala, India, Kenya, Malawi, Mali, Mozambique, Pakistan, Rwanda, Senegal, Somalia, Togo	• Food surplus area in food exporting country • Urban area in exporting country that has weather similar to surplus agricultural area • Includes markets in Afghanistan, Brazil, Guatemala, Kenya, Mexico, Mozambique, Pakistan, Peru, Senegal, Somalia, Thailand, Uganda, Zambia

Note
Markets and commodities are treated independently, so countries will appear multiple times according to the behavior of different markets within their borders.

countries, where the governments maintain marketing reserve boards and attempt to stabilize food prices (Minot, 2012). These countries have larger stocks-to-use ratios than others, and thus we do not expect to find statistically significant impacts of world or local weather shocks (Ihle *et al.*, 2011; Minot, 2011). Minot (2012) found in his analysis on food price variability that these four countries had relatively high food price variability compared to countries with low intervention policies. He states that the uncertainty created by government intervention in maize markets can cause private traders to withdraw from the market, reducing the effect of temporary arbitrage in smoothing prices over time. Other researchers have also suggested that active intervention by the government in food markets, particularly when it involves price controls or unpredictable purchases and sales, discourages private traders from storage, domestic transport or international trade in staple food grains (Chapoto and Jayne, 2009; Byerlee *et al.*, 2006). There are markets within each of these countries, however, that are affected by both weather and international prices, so the impact of these programs varies across markets and time periods.

There is a larger set of locations that are in countries that did not actively control food prices, but that are not affected by either international prices or local environmental dynamics.

This set can be further divided into location-commodity pairs that include commodities that are lower down the supply chain and are low income, and those that involve commodities that are processed products (e.g., wheat flour in Minsk, Belarus or Yerevan, Armenia) and are consequently influenced by a more complex constellation of determinants than have been modeled here. They are different from the set of location-commodity pairs that report the price of more basic products.

Low-income countries with commodity prices that are not affected by either weather or international prices shocks are characterized by markets that often function less efficiently than markets elsewhere (Kshirsagar, 2012). For example, Aker *et al.* (2010) showed that trade frictions due to ethnic differences between traders introduce market segmentation even within national boundaries. Brown *et al.* (2012) showed significant regional price differences between regions, suggesting a wider prevalence of these and other trade frictions. There are also several countries in this category that have been affected by conflict (e.g., Chad, Sudan) or droughts and/or other natural disasters (locations in or near the Sahel, Haiti).

Markets in Tanzania are typically quite well connected with other urban areas and Tanzania has not had a significant conflict in its recent past. Many markets are separated from the main maize producing area in the country (Songea-Mbeya) because of high transport costs and, in addition, Arusha serves the Nairobi market, which is subjected to active government price control (Ihle *et al.*, 2012). We could gain a better understanding about local food price dynamics in these locations if we had a broader set of prices and commodities, and include more examples from each of these categories.

Locations affected by local weather shocks but not by world prices

Locations that are affected by local weather anomalies but are unaffected by world prices are typically isolated food surplus locations. These locations are characterized by at least one of two features. Either food production is significantly higher than what is typically used to support a given population density and/or the area is genuinely isolated so that the band between the export parity and import parity is extremely large. Songea, Tanzania is a good example of a location that produces a food surplus but is faced with transport constraints. Garissa, Kenya is an example of location that probably consumes less per capita, but due to transport constraints has local markets that are fairly independent and are affected by local weather shocks but not international price shocks. These locations also experience significant price seasonality due to increases in prices during the growing season and sharp declines after the harvest during periods of surplus (Alderman and Shively, 1996).

The data also show situations when sharp declines in local prices that accompany unexpectedly large harvests can be observed. Clearly, a large harvest is only a problem when transport costs and storage are both infeasible. The risks associated with large weather shocks can partially be mitigated if storage capabilities (at different levels of aggregation) can be improved and transport constraints are alleviated.

Locations affected by world prices but not by local weather shocks

While there are several location-commodity pairs that are influenced by world price shocks and not by weather shocks, three facts are worth noting. When all commodities are evaluated, rice is the dominant commodity that appears to reflect changes in world prices. This is due to its (relatively) higher value to weight ratio. Consequently, it is profitable to import rice, while arbitrage opportunities for coarse grain trade are significantly lower. Further, several countries (many in West Africa) consume rice, and need to import rice to meet domestic consumption needs (Moseley *et al.*, 2010). Second, world maize prices do influence local price formation in Latin America, and thus these countries' maize prices are affected by international price shocks. These countries are more open and have better transport infrastructure than those in Sub-Saharan Africa. Finally, world wheat prices also influence domestic prices in parts of Eastern Europe and Central Asia as well as in South Asia. Table 7.3 shows the results of a model run using maize prices in non-African countries that shows the influence of international maize prices or domestic NDVI increases.

Locations affected both by world prices and by local weather shocks

In the maize results provided in Table 7.3, we showed that weather and price shocks often interact. Although in many of the model results we do not see a big improvement in the market functioning for Maize in Africa when including international prices, there are a few markets where the two interact significantly. These locations are typically well-connected food surplus locations in countries that trade internationally. Many commodity-market pairs show a slight improvement when NDVI and international price shocks are used together.

When we use all data available and explore the impact both of weather and of international shocks on price dynamics, we find that the relationship of local food prices with shocks can vary within a region and within a country. Plate 22 shows a map that categorizes markets into those that are affected by both weather and international price shocks, and those that are not. West African markets in Mali, Niger and Burkina are not affected by international prices (and thus are not flagged as being affected by both) because of their relative isolation from international markets. East African markets, however, are affected by both kinds of shocks and are particularly sensitive to local weather dynamics. The South Asian markets in Afghanistan, Pakistan and India also show sensitivity to both kinds of shocks. When the interaction between local and global shocks occurs at the same time, households can experience extremely intense food security stress (Garg *et al.*, 2013; Bradbear and Friel, 2013).

TABLE 7.3 Model errors and percent increase of maize prices and NDVI values

Country	*Global price increase (%)*	*Anomalous NDVI increase (%)*	*Forecast RMSPE (%)*
Kenya	0.11 (0.27)	–1.29★★ (0.65)	6.3
Uganda	0.36 (0.46)	–2.32★ (1.21)	26.2
Mexico	0.33★★★ (0.12)	–0.45 (0.39)	10.4
Cameroon	–0.09 (0.18)	0.05 (0.70)	4.7
Guatemala	0.23★★ (0.1)	0.43 (1.24)	6.6
Chad	0.21 (0.27)	–3.2★★ (1.5)	28.9

Note
Significance is denoted with ★★★, percent change is given in parentheses.

Implications for policy and response

The implications of this economic model are that an improved understanding of the policy implications of simultaneous shocks can be estimated, and this knowledge could be used to improve social welfare. Rural economies operate in a dynamic, complex environment with multiple stressors. Many of the influences to vulnerable rural livelihoods are not observable and change rapidly. Data on food price time series can be usefully combined with spatially explicit satellite remote sensing information about climate variability to provide more accurate assessment of the status of rural livelihoods. This information can be used to improve early warning of impending shocks to a food system through organizations like FEWS NET. As the food price time series extends to additional months, the model will provide additional information and allow for quantitative comparison across multiple countries.

Model information about the interaction of weather and food price shocks could complement existing analyses to qualitative assessment of livelihood and entitlements of vulnerable populations. Regions with local food price movements that are unusual or that do not respond in anticipated ways could indicate the effectiveness (or lack thereof) of private traders to supply markets that are experiencing food deficits. Humanitarian organizations need a quantitative approach to flag markets in regions experiencing drought or other widespread food production shock. If local private traders are doing their job and food is flowing into a market to respond to high food prices, then outside help is not immediately necessary. If this is not happening for some reason, then outside intervention may be required. Rapid assessment of the response of a market and the broader region to production shocks would be an important contribution.

The model analysis would also provide an improved baseline for poverty assessment. Traditional measures of poverty are based on consumption aggregates at the national level. The analysis presented here shows that each market is different and that aggregation at the national level, where regional and capital city markets are grouped, does not really make sense given the heterogeneous response to shocks these markets show. Poverty analysis that includes information on local food price dynamics (including weather and other shocks) can provide context to poverty evaluations and lead to more nuanced policy conclusions regarding the impact of government programs on rural outcomes (Deaton and Zaidi, 2002).

Summary

This chapter described the various ways food prices can be related in a modeling framework and presented a model using a state space approach to model local price dynamics, which was popularized in the economics literature by Harvey (1989). Economic impacts of changing supply and demand, and how these impacts are affected by the market's relative connectedness to the international markets were described. A conceptual typology that provides the influence of the international commodity markets and the local climate variability on local food prices was presented, along with a discussion of the impact of these various influences on food price creation.

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8

ENVIRONMENTAL AND NUTRITION OUTCOMES

Chapter objectives

Climate variability will likely continue to affect agricultural production, but through what other pathways will environmental change affect food security and nutrition outcomes in the developing world? The most food insecure members of society are also the most vulnerable to disease, extreme events, conflict, lack of access to credit, education and health resources, and other problems of distribution. Malnutrition itself changes the immune system, increasing the likelihood that the individual will have more diarrheal, communicative and vector-borne diseases during their lifetime. Prolonged malnutrition degrades the individual's utilization of food, reducing food security even if there is adequate access and availability later in life. This chapter will explore what is known about the causes of malnutrition and its linkages with environmental and climate dynamics. Climate variability and price spikes have broader societal consequences beyond simply food security impacts. Understanding these consequences is critical for designing appropriate interventions to improve human welfare.

Links between the state of natural systems and human health

Climate variability is just one perturbation of the natural system upon which agriculture and food production rests. Ecosystems can become degraded with the expansion of human activity. As Myers *et al.* (2013) state:

> with the human population having just exceeded 7 billion people, accompanied by rapid growth in per capita consumption, humanity's growing ecological footprint is dramatically altering the planet's land cover, rivers and oceans, climate system, biogeochemical cycles, and the functioning of its ecosystems.

These changes have resulted in profound and widespread alterations in ecosystem functioning that changes how these ecosystems respond to variations in the climate. Changes seen in natural systems are relevant to human health outcomes in the following categories (Myers *et al.*, 2013):

- reductions in biodiversity;
- changes in land use and ecosystem function;
- alterations in the way wildlife, domesticated animals and humans interact;
- climate change.

The transformation of the natural world has been done to serve human needs. These changes have led to enormous increases in the amount of food available per capita, allowed access to minerals and metals needed for industrial activity, increased access to energy and water sources and allowed harvesting of all manner of renewable resources, from trees, kelp forests, shellfish, to a wide variety of fish stocks (Kates *et al.*, 1990). This transformation has allowed the human population to increase exponentially while simultaneously increasing the standard of living and reducing the poverty rate (Myers and Patz, 2009).

The Millennium Ecosystem Assessment focused attention on the damage all this development has done to ecosystems around the world, stated that without a change in the way people used natural resources, it was likely that the progress seen in human welfare over the past centuries could not be sustained (Reid *et al.*, 2005). The accelerating degradation of natural resources and ecosystems drives an urgent need to alter policies to ensure that the risk of catastrophic changes to ecosystems is averted. As ecosystems transform, they become more vulnerable to perturbations of climate, reducing their resilience and productivity. The assessment brought together literature on the likely impact on human health caused by degraded resources, and focused attention on the impact these changes would have on the poorest and most vulnerable groups. Researchers began focusing on providing quantitative evidence that links environmental change to human health, an effort that is still ongoing.

Environmental change and nutrition

Food security and nutrition linkages are strong, particularly for the need to provide adequate calories and protein to the world's growing population. Because most chronically hungry people in the world are also among the over one billion people who live in absolute poverty, increasing global food production is only part of the solution (Myers and Patz, 2009). Many of the food insecure are too poor to access global food markets and depend on local food production. Local ecological constraints can drive hunger, disease and death in these poor communities, even if global food production exceeds demand in the aggregate (Myers and Patz, 2009). Nutrition is the intake of food, considered in relation to the body's dietary needs. Good nutrition, or an adequate, well-balanced diet combined with regular physical activity, is a cornerstone of good health. Poor nutrition can lead to reduced immunity, increased susceptibility to disease, impaired physical and mental development, and reduced productivity (WHO, 2013).

Soil infertility is already driving reductions in yield in regions that do not use adequate fertilizer and can significantly impact local food production (Sanchez, 2002). Rates of land degradation in agricultural regions are not well known, but recent work on erosion rates indicate that modern, mechanized tillage agriculture is causing erosion at rates that exceed soil formation by one to two orders of magnitude (Montgomery, 2007). The long-term impact of these changes is poorly understood.

For example, in savanna regions of Africa, land degradation has long been conceptually difficult to assess, since in many non-equilibrium systems the likelihood of the transition of ecosystems from a productive to non-productive state due to overuse has been poorly understood (Blaikie and Brookfield, 1987; Ellis, 1987). Recent research using satellite remote sensing has found that degraded areas were no less stable or resilient than non-degraded areas when studying land degradation in the former homeland areas of South Africa. The productivity of these degraded areas was less, in that they produced less forage per unit rainfall than intact ecosystems, but there was no trend or trajectory towards "desertification" or catastrophic reduction in ecosystem function due to over-grazing (Wessels *et al.*, 2004). Our inability to quantify the risk of soil degradation to the ultimate productivity of ecosystems in the tropics greatly reduces our ability to predict the impact of soil degradation across broad regions of savanna in Africa, Asia and the Americas.

Markets and health services tend to buffer communities from the direct impact of ecosystem degradation. Markets allow the purchasing of natural resources such as energy, food and building materials from elsewhere, reducing the impact of local scarcity. The causal chain from global environmental change and climate variability to health impacts is often complex and may not be immediately observed. Land use and climate change do impact human health directly as well as services that ecosystems provide, such as clean water or waste disposal, which indirectly impact human health (Myers and Patz, 2009). Figure 8.1 shows a conceptual diagram derived from Myers and Patz describing the factors that protect a community from environmental or weather shocks.

Biodiversity and human health outcomes

Although often viewed as a "first world" concern when focused on charismatic mega-fauna such as tigers and polar bears, biodiversity is also very important to poor populations in the

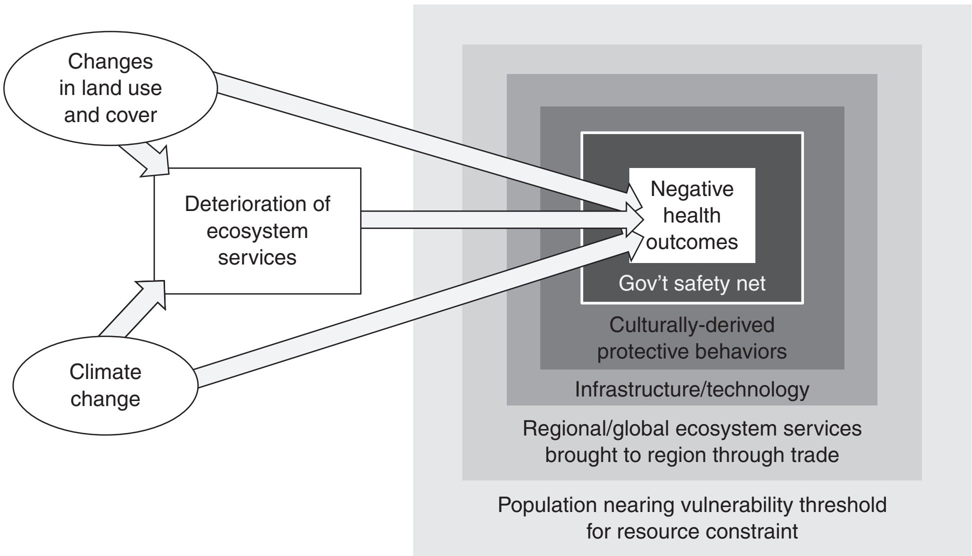

FIGURE 8.1 Schematic describing the relationships between environmental conditions and negative health outcomes, and the insulating effects of culture and society (source: Myers and Patz, 2009).

developing world. Rural food insecure populations have been shown to rely far more on protein and nutrients from wild meat hunted for consumption than previously thought. Golden *et al.* (2011) found that children in Madagascar would experience a 30 percent higher risk of iron deficiency anemia if they did not have access to meat from wild animals. This study is a hallmark of the detailed, long-term, focused research needed to demonstrate the precarious situation in many communities. Anemia increases the risk for sickness and death from infectious disease, reduces intelligence and learning, and reduces lifelong tolerance for physical activity (Lozoff *et al.*, 2006). Long-term monitoring of hemoglobin levels and wildlife consumption in children showed that those from the poorest income levels would be three times more likely to become anemic if access to wildlife was restricted. These poor households are also most likely to be affected by broader nutrition effects of weather-related food production declines. The expansion of these human populations has resulted in the decline of animal species diversity and population levels in these regions.

Golden *et al.* (2011) describe the difficulty of supplying alternative sources of protein for these communities. Balancing the need for economic development, biodiversity conservation, human health and local rights are enormously difficult in a remote and undeveloped region such as northeastern Madagascar. These goals are incongruent with each other, requiring either out-migration by portions of the human population or degradation of the natural resources upon which the human communities rely. There are unfortunately few examples of successful management of natural resources in such resource-limited areas. Site specific and community specific solutions must be developed that are tailored to the problems seen in the region, although solutions that meet all the objectives above are unlikely to be cost effective (Golden *et al.*, 2011).

Anemia is not the only nutritional issue that results in poor outcomes. Alderman *et al.* (2006) showed that when nutritional shocks were experienced before the age of three, long-term consequences on educational attainment and on height were observed. The study, conducted in Zimbabwe, showed that individuals who experienced nutritional shocks as children had a loss of 14 percent of earnings over their lifetime due to their smaller physical stature and vitality (Alderman *et al.*, 2006). This link between stunting and reduction in the ability to fight off disease and poverty has long underpinned the perceived need to reduce or eliminate food insecurity and hunger (Figure 8.2).

Chronic hunger leads to malnutrition that causes damage to human development in the first two years of life. This damage is irreversible and, according to Atinmo *et al.* (2009), "is linked to lower intelligence and reduced physical capacity, which in turn diminishes productivity, slows economic growth, and perpetuates poverty." Thus the communities who experience hunger and food security crises are also the most likely to have them reoccur because of poor economic development, reduced productivity and lower physical capacity in regions where physical labor is how most work is done. The United Nations estimates that one out of every six preschoolers in developing countries, 100 million children under the age of five, are under weight (WFP, 2013). The problem is large and complications such as conflict, lack of job opportunities, poor health, inequitable trade policies, unsustainable management of natural resources, gender discrimination, and recurrent natural and man-made emergencies contribute to the lack of progress on the issue (Atinmo *et al.*, 2009).

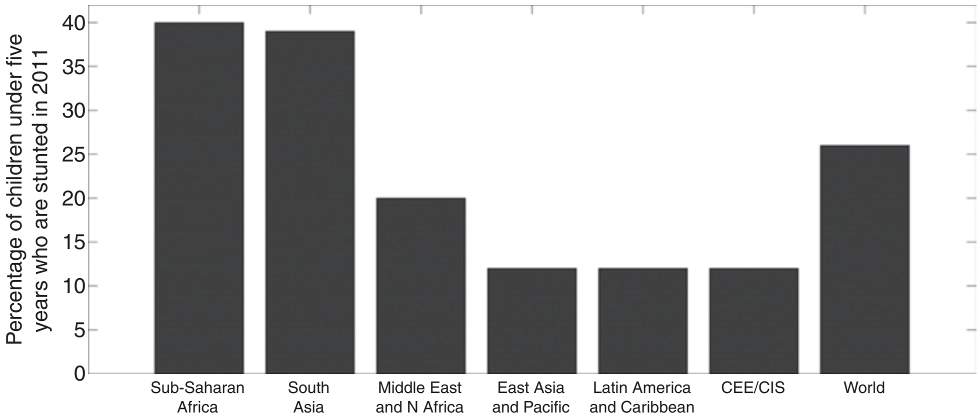

FIGURE 8.2 Percent of children under five years who are stunted in 2011 by region (source: modeled data from childinfo.org, derived from United Nations Children's Fund, World Health Organization, World Bank, UNICEF-WHO-World Bank Joint Child Malnutrition Estimates, 2011 revision (completed July 2012)).

Note
CEE is Central and Eastern Europe, and CIS is Commonwealth of Independent States (former USSR).

Food access and nutrition outcomes

How can we measure food insecurity? There are two comprehensive approaches to measuring food insecurity. One approach involves measurement of the anthropometrics of representative samples of the population (e.g., Demographic and Health Surveys). The other involves measurements of aggregate household (and/or) individual consumption (per capita) of representative samples (e.g., the World Bank's Living Standard Measurement Surveys). However, both these methods require resources and time and, as a result, these surveys are rarely conducted more than a few times in a decade for a given country. A central limitation of using anthropometry in assessing child nutritional status is its lack of specificity, as changes in body measurements are sensitive to many factors including intake of essential nutrients, infection, altitude, stress and genetic background.

Although critical for long-term assessments, these surveys are too slow a process to be used to identify local increases in food insecurity. Consequently, while surveys are essential to understanding both the mechanisms behind changes in food insecurity and the attendant long-term negative impacts on health and household assets, there is a compelling need for more integrated analysis of the causes and consequences of food security crises (Barrett, 2010).

By using remote sensing observations to measure changes in the environment, we can focus on understanding the impact of large-scale changes on nutrition outcomes. Although food security assessments such as food access and food availability are important, it is informative to see the direct impact of observable environmental change on nutrition outcomes. If the odds of malnutrition increase with drought, for example, this will have a broad impact on a wide set of nutrition indicators as well as on economic activity. How we can measure those indicators both remotely and locally is a critical question.

Dimensions and indicators for analyzing vulnerability to food security crises

Research in the 1980s by a number of authors led to vulnerability assessments that describe the dimensions and indicators of vulnerability to famine and food security crises (Downing, 1991). Table 8.1, derived from Downing (1991) describes how these indicators are used to assess crises and to identify an appropriate response. Although most food security assessment is done at the household and community scale, famine occurs at the regional and national level. For decades, the national food balance sheet was the primary means by which a deficit in production and import capability could be used to diagnose an impending food security crisis. A food balance sheet presents a comprehensive picture of the pattern of a country's food supply during a specified reference period. The food balance sheet shows the sources of supply and its utilization for each food item or primary commodity and a number of processed commodities potentially available for human consumption.

The groundbreaking work of Amartya Sen showed that an understanding of food availability or supply must be coupled with that of food access, or ability to purchase food when necessary (Sen, 1981). Stable access, through a household's production of food, exchange, entitlements, gifts, loans, purchase or other means all contribute to its ability to access enough food. These may be independent, but are often highly related to overall supply of food at the regional and national level (Frankenberger, 1992). Each household has its own unique vulnerability to shocks. Aggregating over all households in a community or region gives you the food security of a region (Table 8.1).

These vulnerability factors can be used to develop indicators that link environmental and market conditions to outcome – nutrition and health impacts of poor food security situations. Conceptual models of food security implicitly or explicitly determine indicators of household food security. Understanding the process that causes the food crisis is critical for diagnosing and quantifying the impact of a particular shock on food security outcomes. FEWS NET and GIEWS both produce documents with extensive text that describe the shock and its likely impact on a wide variety of different populations and economic groups.

The household economy approach of food security assessments provides an understanding of these resources, including geography, agro-ecology, ownership of productive assets and inter-household relationships. The agro-ecology of an area determines what people are able to produce or grow while access to productive assets and inter-household relationships dictate the extent to which people are capable of meeting their food and cash needs. The degree to which households are able to *maintain access* depends on their capacity to withstand and recover from hazards that hinder regular access to food and income (FEWS NET, 2012).

In 2011, FEWS NET and the World Food Programme adopted the Food Insecurity Severity Scale, which is part of the Integrated Food Security Phase Classification (IPC). The IPC is a tool for food security analysis and decision support that allows for standardized tests and comparisons across multiple regions and populations. The IPC integrates food security, nutrition and livelihood information into a common classification of the severity of acute food insecurity outcomes, and can be used to highlight priority areas and populations in need of emergency response that have been identified based on food security analysis (IPC, 2012).

The IPC is a set of protocols (tools and procedures) to classify the severity of food insecurity and provide actionable knowledge for decision support. The IPC (2012) consolidates

TABLE 8.1 Household vulnerability assessment matrix

Risk of an event	*Ability to cope*			
Shocks/trends	*Household characteristics*	*Access to resources*	*Production/income opportunities*	*Support structures*
Current vulnerability *Crop and livestock production* (drought, soil conditions, pests) *Market risks* (market infrastructure, price fluctuations, food shortages) *Political risks* (conflict, war)	Composition Education Health status Out-migration	Access to land Access to labor Liquid Assets (cash or income) Productive Assets (tractors, wells, seeds, etc) Common property resources (wild food, firewood) Food stores	Crop/livestock production Wage labor Other income sources Seasonal migration	Community support mechanisms NGOs Government support Access to health care and social services
Future vulnerability (environmental degradation land pressure out migration)	Demographic changes	Land tenure changes	Employment trends Economic growth	Support structure changes Government spending

Source: derived from Frankenberger, 1991.

TABLE 8.2 Definitions and thresholds for wasting, stunting and malnutrition from the IPC framework

Term	*Importance*	*Meaning*	*Critical levels*
Wasting	Weight-for-height index (w/h)	While wasting is a direct outcome of nutritional and health status, limitations in its use and interpretation include: (1) wasting can be a late outcome indicator of a crisis, and response mechanisms based on wasting can be too late for meaningful action; and (2) in populations where levels of acute malnutrition are high outside times of acute crisis, levels during periods of crisis can be difficult to interpret.	A key reference threshold for Humanitarian Emergency, where wasting is >15% of children under the age of 5. Making adjustments to fit the IPC phases, the reference threshold for Famine/Humanitarian Catastrophe is >30% (Howe and Devereux, 2004)
Stunting	Height-for-age growth retardation	"Growth failure in a child that occurs over a slow cumulative process as a result of inadequate nutrition and/or repeated infections" (IPC, 2012). As such, levels of stunting indicate overall poverty and chronic malnutrition, of which food insecurity may be a contributing factor. The IPC includes stunting as it is a measure of long-term effects of food security status; whereas wasting is a better measure of acute and highly dynamic situations.	The reference threshold of >20% is used to classify areas that are Chronically Food Insecure. Percent with height for age <–2 Z scores: low (<20%), medium (20–29%), high (30–39%) and very high (≥40%) (Delpeuch, 2005; Young and Jaspers, 2009)
Malnutrition	Severe acute malnutrition is defined by a very low weight for height (below –3Z scores of the median WHO growth standards), and by visible severe wasting, or by the presence of nutritional edema.	Acute malnutrition is a direct outcome indicator of recent changes in nutritional status. High or increasing levels of acute malnutrition in a population indicate current or recent stress at individual or household level.	"5–8% indicates a worrying nutritional situation; 10% corresponds to a serious nutrition situation" WHO provides guidance as follows: low (<5%), medium (5–9%), high (10–14%) and very high (≥15%) Howe and Devereux (2005) reference "Famine Conditions" as 20–40%, and "Severe Famine Conditions" as >40%.

Source: derived from IPC, 2012.

wide-ranging evidence on food insecure people to provide core answers to the following questions:

- How severe is the situation?
- Where are areas that are food insecure?
- How many food insecure people live in these regions?
- Who are the food insecure people in terms of socio-economic characteristics?
- Why are the people food insecure?

The IPC has four functions: to build technical consensus, to classify severity and causes, to communicating severity for action, and to provide quality assurance. The IPC is the descendent of the food security indicators developed by Frankenberger and Downing in the early 1990s, but allows for a much greater focus on outcome than the more process-oriented metrics that were used previously. The IPC also brings an analytical framework that builds from four widely used conceptual frameworks: the Risk = f (Hazard, Vulnerability) used by the Disaster Risk Reduction (DRR) framework, Sustainable Livelihoods Approach, Nutrition Conceptual Model and the four "dimensions" of food security (availability, access, utilization and stability).

Understanding what the nutritional status and mortality indicators are and being able to link them to environmental dynamics as well as food access is an important aspect of the work. Table 8.3 provides a description of indirect measures of nutritional status and where an

TABLE 8.3 Indicators of nutritional status from the IPC Handbook

Parameter	*Indirect indicator*	*Source*
Nutritional status	Underweight	Multiple Indicator Cluster Survey (MICS), Demographic and Health Survey (DHS), Nutrition studies (e.g., Centre for Research on the Epidemiology of Disasters, Complex Emergency Database (CRED CEDAT database)
	Admissions to feeding programs	Health Information System Data Sentinel site data
	Prevalence of night blindness (children under 5/pregnant mothers)	Demographic and Health Survey (DHS) (pregnant mothers)
	Prevalence of low birth weight	Multiple Indicator Cluster Survey
	Household iodized salt consumption	Multiple Indicator Cluster Survey
	Iron and folic acid supplementation programs to pregnant women	Multiple Indicator Cluster Survey and the Demographic and Health Survey (DHS)
	Vitamin A supplementation programs to children under 5 and/or breastfeeding mothers	Multiple Indicator Cluster Survey

organization may acquire the data. Most indicators are based on changes in government-collected statistics such as admissions to feeding programs or iodized salt consumption, which may have only a tenuous connection with actual malnutrition rates which require examination of individual children. Nearly all food crises involve direct food assistance in the form of free food, or in monetary support so that households can purchase their own. If nutrition problems are not linked to either availability (supply) or access (cost), then food security programs that only provide extra food are extremely unlikely to be effective in reducing malnutrition and stunting, and will fail in their goal to break the cycle of poverty and poor nutrition.

Causes of malnutrition and stunting

A case study from South Sudan, published in 2011, provides some insight into the causes of malnutrition. A nutrition causal analysis was commissioned to understand the causes of the poor nutrition situation in South Sudan during the 2008–2011 period. A nutrition causal analysis provides a multi-sectoral overview of the contributing factors affecting the nutritional status within a given community. The analysis had several objectives (Woldetsadik, 2011):

- to assess the magnitude of acute malnutrition in children aged 6–59 months;
- establish an association between malnutrition and contextual variables;
- to determine the relative importance of different factors that influence nutritional status; and
- conduct a logistic regression analysis and establish causality pathways based on the statistical association between the nutritional status of children and the set of associated underlying causes (socio-economic, consumption related, hygiene related, environmental and health related).

The study used a randomized sampling of households in 2008 and 2011. The sample was taken using a proportion formula for follow-up surveys considering the higher confidence interval of the acute global acute malnutrition prevalence in 2008 and 2011. Household selection was based on two-stage cluster sampling with probability proportional to size. Both anthropometric and contextualized data were collected simultaneously from 48 clusters during the study. In total, the data of 572 children from the same number of households were collected. Univariate, bivariate and multivariate analysis were performed using the frequency tabulation, chi-square factor analysis, cluster analysis and logistic regression (Woldetsadik, 2011). Further details of the methods and sampling can be found in the report, which can be downloaded from the Global Food Security Cluster website, and other sites online.

The average annual acute malnutrition found in the analysis was at 19 percent, which is above the emergency threshold set by the United Nations World Health Organization of 15 percent.

The study found that the following parameters were significantly associated with acute malnutrition in South Sudan:

- educational status of the caretaker;
- mother's occupation;
- household water treatment practice;

- hand-washing behavior;
- child illness within 15 days before the survey especially diarrhea and malaria incidences;
- assistance during delivery and place of delivery;
- availability of prenatal care; and
- excretal and household waste disposal.

Although the model included information on household food insecurity, no food availability data or environmental parameters such as production or weather data were included in the regression. These variables were included in a measure of food insecurity, which was described with the Household Food Consumption Score (Deitchler *et al.*, 2011). The consumption score provides responses to questions recalling inadequate access to food, focused on capturing: (1) anxiety about household food supply; (2) insufficient quality, which includes variety, preferences and social acceptability; and (3) insufficient quantity and intake of food and the physical consequences of this deficiency (Deitchler *et al.*, 2011).

Although the study found that the prevalence of acute malnutrition is higher among children with low dietary diversity, the analysis found no significant relationship between malnutrition, household hunger scale and the food consumption score. This means that the rate of acute malnutrition was the same in households with poor or extremely low food security and those adequate or acceptable levels of food security. Access to food also did not affect acute malnutrition rates, thus the entirely health-related, feeding practice and sanitary findings of the study were the causes of malnutrition in the region.

Woldetsadik also reported on seasonal changes in malnutrition rates as well as changes through time. He showed that the pre-rainy season and rainy season had much higher rates of malnutrition than post-harvest. In the months preceding the rains both fish and milk, major components of the local diet, are at an annual low. Cattle are grazing in the distant lowland region and as the rivers and pools dry up, fish no longer supplements the diet. Therefore as crop stocks continue to be eaten the population becomes increasingly vulnerable to food shortages (Figure 8.3). These seasonal increases reflect the seasonal price increases described in Chapter 6, and are likely due to a number of factors, not just the diversity and amount of food.

The conclusion that can be reached from this analysis is that providing more food or income support for purchasing more food in the markets would not lead to lower malnutrition rates for the households described in the study. In fact, little or no change in the acute malnutrition rates has been seen in South Sudan over the past decade, despite huge increases in the amount of assistance to Sudan from 2005 to 2008 (FAIS, 2012), and substantial amounts going directly to South Sudan after the end of the conflict in 2011. Thus although more information about market functioning and environmental dynamics would be useful, much more will be needed than simply information to address the needs of the poorest and most food insecure in regions like South Sudan.

Evidence on environment and nutrition outcomes

In addition to the causes of malnutrition in a particular region, the links between environmental change and nutrition outcomes over the longer term are poorly described in the literature. At a larger level, the survival and well-being of human populations remain fundamentally dependent on ecosystem services – including clean water, plant and animal species for food

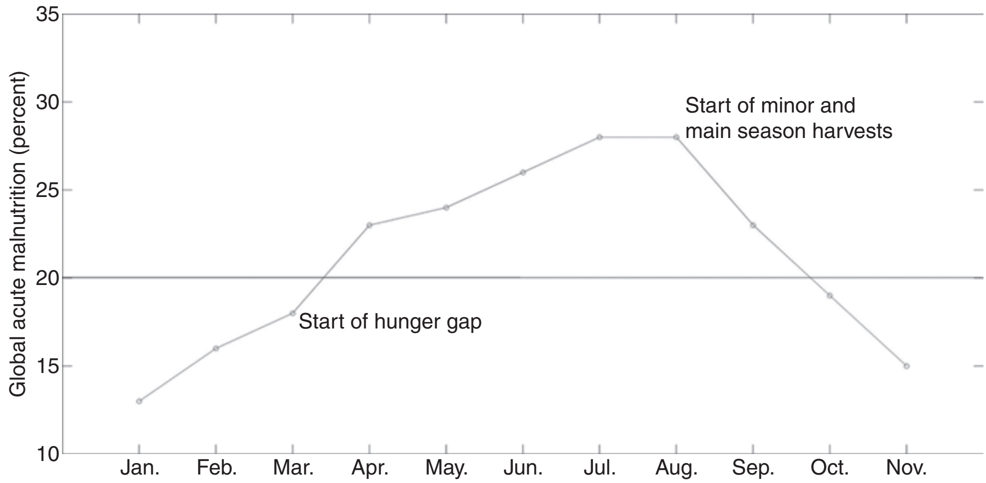

FIGURE 8.3 Monthly trends of global acute malnutrition prevalence in northern Bahr el Ghazal state, South Sudan (source: Woldetsadik, 2011).

and medicine, pollination, fuel and air purification. Replacing these natural services with technology-based functions greatly increase the need for substantial investments in infrastructure and robust institutions to support it. Research looking at nutrition outcomes and dietary diversity that explicitly includes information on environmental change while controlling for variations in food production caused by the weather should be interesting to explore here. However, because of the enormous number of reasons for poor health of any one individual, including personal history, income, ethnic affiliation, education, personality and political isolation, identifying these connections will be difficult.

A study by Johnson *et al.* (2013) brings together datasets on forest change from satellites and child dietary diversity, nutrition status and illness (diarrhea) in Malawi. The hypothesis that was being tested with this study was that degraded environments, as proxied by deforestation and low percentage of forest cover in Malawi, result in degraded ecosystem services, which then open pathways to child undernutrition and consequently poor health. Conversely, the report hypothesized that intact environments, as represented by higher percentages of forest cover and protected areas, will have comparatively better capacity to provide essential ecosystem services, which then translate into improved human nutrition and health outcomes.

If the existence of a causal relationship between forest cover and improved health status is hypothesized, then using household surveys and remote sensing data is a way of testing the relationships. There is a clear selection that goes into where people end up living, and the poorest/worse-off may end up living in areas with less forest cover because these are undesirable places to live. However, forest cover characteristics may have nothing to do with why they are in poor health but is simply associated with places where poor people live. Exploring these relationships is of interest, however.

To conduct the analysis, the report linked satellite remote sensing data and GIS-based information on proximity to conservation areas to population and health data from Malawi. The association between child health and nutrition outcomes and proxies for biodiversity (percent forest cover and proximity to a protected area (PA)) and biodiversity change (decadal forest cover loss or gain) using multivariate methods was assessed. In this study, the impact of weather and seasonality was removed from the analysis by using a "dummy" variable based on the NDVI for the year/month that the data were collected.

Demographic and Health Survey (DHS) information

Demographic and Health Surveys are the gold standard source of comparative quantitative data on population, health and nutrition indicators across developing countries. They are nationally and sub-nationally representative household surveys with large sample sizes that provide detailed information on these topics by interviewing eligible respondents in each selected household (women age 15–49 and men age 15–59). The data also include information on household and other socio-economic characteristics. DHS data are collected from probability samples selected using a stratified two-stage cluster design. DHS observations are weighted to be representative at the national level, according to urban/rural residence, and at the provincial level (departments, states). More than 300 DHS surveys have been implemented in over 90 countries since the inception of the USAID-funded project in 1984.

Since the mid-1990s, the DHS project has collected geographic information in most surveyed countries at the level of the cluster. The latitude and longitude of each household cluster allows the connection of environmental information to the survey results. During fieldwork activities to conduct the DHS surveys, the global positioning system (GPS) coordinates for the approximate center of the populated area surveyed (cluster centroid) are collected using hand-held GPS units. During data processing, GPS coordinates are displaced to ensure that respondent confidentiality is maintained. The displacement is randomly applied so that rural points contain a minimum of zero and a maximum of five kilometers of positional error. Urban points contain a minimum of zero and a maximum of two kilometers of error. A further 1 percent of the rural sample points are offset a minimum of zero and a maximum of ten kilometers. This random shift eliminates the possibility of calculating exact distances from the cluster to other locations of interest, and requires that a buffer of some type is used when linking the DHS and landscape/geophysical data (Brown *et al.*, 2013).

Malawi and ecosystem services

Malawi has very high rates of deforestation, child undernutrition and child mortality, as well as a high level of dependence of the population on ecosystem services. Malawi has lost almost 600,000 hectares of primary forest between 1990 and 2005, with regional deforestation rates as high as 3.4 percent per year (Berry *et al.*, 2009). Over 80 percent of Malawi's population is rural and highly dependent on natural resources for food, fuel and maintenance of livelihoods (United Nations, 2011). A total of 47 percent of children are stunted, and the under-five mortality rate is 112 deaths per 1,000 live births (DHS, 2011).

The analysis used a multivariate unweighted binomial logistic regression to examine the correlation between variables of interest (forest cover or decadal change in forest cover) and our selected outcome variables (severe stunting, dietary diversity, consumption of vitamin-A rich foods or experience of diarrhea), while controlling for confounding factors for which data were available: child's age, water source, toilet facility, mother's education, wealth quintile, NDVI and whether or not the family has migrated into or out of the area. Weather and food production variability due to moisture conditions were controlled using the monthly NDVI for the month/year during which the household was surveyed. The independent variables of interest included a categorical variable representing the percentage of forest cover associated with each DHS sampling cluster (0–9 percent, 10–19 percent, 20–29 percent, 30–39 percent, 40–49 percent and 50–59 percent forest cover), and another categorical variable reflecting decadal changes in forest cover over the period 2000 to 2010 (no change, net forest loss and net forest gain). Forest cover data were derived from the MODIS vegetation continuous fields at 250-meter resolution (DiMiceli *et al.*, 2011). The results are expressed in odds ratios that indicate the associations between the independent and dependent variables without attributing causality (Johnson *et al.*, 2013).

The study found that children living in DHS clusters characterized by a net loss of forest cover over the past decade demonstrated a 19 percent decrease in the odds of having a diverse diet and a 29 percent decrease in the odds of consuming vitamin-A rich foods, relative to the reference category (no net change in forest cover) (Figure 8.4). Conversely, children living in communities with higher percentages of forest cover had increased odds of consuming vitamin-A rich foods and decreased odds of experiencing diarrhea. Children living in clusters with a net gain in forest cover from 2000 to 2010 demonstrated a 34 percent decrease in the odds of experiencing diarrhea. No statistically significant associations were found between the environmental variables and child stunting.

These results show that environmental dynamics and change are associated with different nutrition outcomes, even if food availability is not a primary factor. The pathways between environment and health are many. One study in Malawi will not conclusively demonstrate a relationship between intact ecosystems and health outcomes, and thus the analysis will soon be extended to Nepal, Uganda, Kenya and Mali. As the work expands to other areas, the associations between food availability, food production and nutrition outcomes will be strengthened.

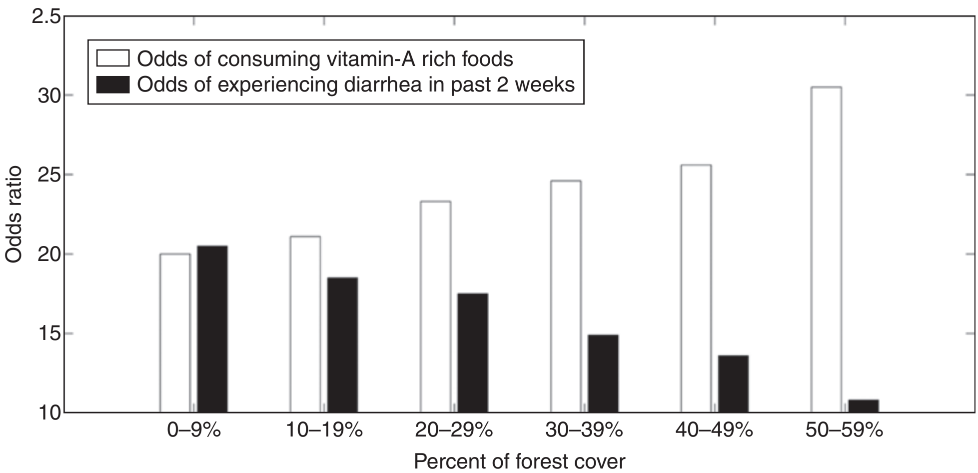

FIGURE 8.4 Results from the Malawi study showing odds of consuming vitamin-A rich foods and of experiencing diarrhea in the past two weeks (source: derived from Johnson *et al.*, 2013).

Food availability and nutrition outcomes: West Africa

Research focused on understanding the consequences of an environmental shock can use a variety of data to estimate nutrition outcomes. Ongoing food aid programs, assistance for childhood feeding, health and other nutrition campaigns, and other activities all affect the nutritional status of children under five years of age (Johnson and Brown, 2013). These efforts to reduce overall food insecurity are occurring during a period of increasing rainfall and resulting vegetation productivity and significant economic growth (USAID, 2012; USDA, 2012). Research bringing NDVI and DHS information together can provide insights into the consequences of climate variability on childhood mortality and nutrition. These outcomes are measured through direct sampling of individual children in a population, and represent nutrition outcomes resulting from broader socio-economic conditions, despite efforts from a wide variety of programs and government interventions. This is a very different scenario from the FAO undernutrition statistics, which are measured indirectly through analysis of national level population and food production statistics, both of which have errors and uncertainties.

NDVI can be used as a variable in a regression analysis to remove the impact of weather and agricultural growing conditions on nutrition outcomes. The study links NDVI to the reference child's date of birth to child nutritional status (stunting and wasting) from DHS variables and child survival data from four countries: Benin, Burkina Faso, Guinea and Mali. The association between environmental conditions (as proxied by vegetative growth) and child survival and nutritional outcomes is assessed using multivariate methods (Johnson and Brown, 2013). This initial research and subsequent variations on these analyses using satellite-derived information on the vigor of the growing season vegetation will allow us to make stronger arguments about how climate change (warming trends and anomalous weather patterns), via its impact on growing conditions, can be expected to affect child nutritional status and survival.

Nutritional status and survival data, as well as other individual-level characteristics were drawn from the Demographic and Health Surveys (DHS; funded by the United States Agency for International Development (USAID)) program for the following surveys: Benin 2001, Burkina Faso 2003, Guinea 2005 and Mali 2001 and 2006. DHS surveys were collected from nationally representative probability samples selected using stratified two-stage cluster designs; more information about each survey can be found in its respective final report (Benin: Institut National de la Statistique et de l'Analyse Économique (INSAE) et ORC Macro 2002; Burkina Faso: Institut National de la Statistique et de la Démographie et ORC Macro 2004; Guinea: Direction Nationale de la Statistique (DNS) (Guinée) et ORC Macro 2006; Mali: Cellule de Planification et de Statistique du Ministère de la Santé *et al.* 2002 and 2007) (Johnson *et al.*, 2013). West Africa is expected to be particularly hard hit by the effects of climate change due to the region's dependence on rain fed agriculture as a primary livelihood, and poor regional capacity to adapt to changing conditions. The four countries have diverse ecosystems, economies and levels of rainfall.

As in the Malawi study, DHS GPS data were overlaid with the average AVHRR NDVI data from July, August and September to extract the NDVI value at each DHS cluster centroid. The methods used were a one-way ANOVA with a bivariate analysis of the relationship between NDVI and the outcome variables of interest, with additional variables to control for confounding factors (Table 8.4). Similar to the Malawi study, the results are expressed in odds ratios that indicate the associations between the independent and dependent variables without attributing causality.

TABLE 8.4 Sample details for Demographic and Health Surveys used in the analyses: Benin 2001, Burkina Faso 2003, Guinea 2005 and Mali 2001 and 2006

Survey	*Rural household response rate*	*Rural individual women's response rate*	*N of rural interviewed women age 15–49*	*N for analysis of survival*[1]	*N for anthropometric analysis*[2]	*N for hemoglobin analysis*[3]
Benin 2001	97.1	96.9	3,835	2,001	1,647	838
Burkina Faso 2003	99.7	96.8	9,463	4,803	3,893	1,465
Guinea 2005	99.6	98.2	5,599	2,756	1,180	1,145
Mali 2001	98.5	95.8	9,340	5,363	4,192	1,296
Mali 2006	99.0	97.1	9,440	5,199	4,252	1,463

Notes

1. Most recent live births to interviewed rural women occurring <36 months prior to the survey.
2. Most recent live births to interviewed rural women occurring <36 months prior to the survey with valid anthropometric measures.
3. Most recent live births to interviewed rural women occurring 6–35 months prior to the survey with valid hemoglobin measures; a representative subsample of children was selected for anemia testing in all surveys.

Figure 8.5 summarizes the results of the analysis. A consistently important variable in these models is mother's education, which reduces the odds of stunting in most countries. Child's age is also important in the regression, as the youngest children are protected to some degree from undernutrition through breastfeeding; as children get older and need to rely on other food sources for the majority of their calories, the effects of food scarcity and insecurity, poor nutritional quality of available foods, as well as increased risk of infections, become apparent.

The analysis shows that NDVI is significantly associated with an increased risk of mortality in the two driest countries: Burkina Faso and Mali. Every unit increase in NDVI was associated with a 13 percent reduction in the odds of mortality in Burkina Faso, and a 7 percent reduction in Mali 2001. However, the NDVI variable is only significant in the 2001 Mali survey, and not in 2006. Across these countries, the variable that is most frequently significantly associated with mortality is birth interval: compared to first births, children who are born after longer birth intervals are significantly less likely to experience mortality. Thus, the association between NDVI as a proxy for crop yield and young child mortality is inconsistent across countries and over time.

NDVI does not have a consistent association with stunting. This varying relationship has been observed in other studies as well (Curtis and Hossain, 1998). In Benin, for every unit increase in NDVI, there is a 40 percent increase in stunting. In Mali 2006 (but not 2001), for every unit increase in NDVI, there is a 12 percent decrease in stunting. NDVI does not have a significant association with stunting in any other country. The reasons for the positive association between NDVI anomaly and stunting in Benin could be many. It could be that the NDVI values are higher because of fewer clouds (and thus less rainfall) and not because of increased productivity. This change may reduce production in some crops such as vegetables that are important for child feeding. Alternatively, there could be an association with disease vectors or increased fungal contamination of the food supply that our analysis cannot uncover.

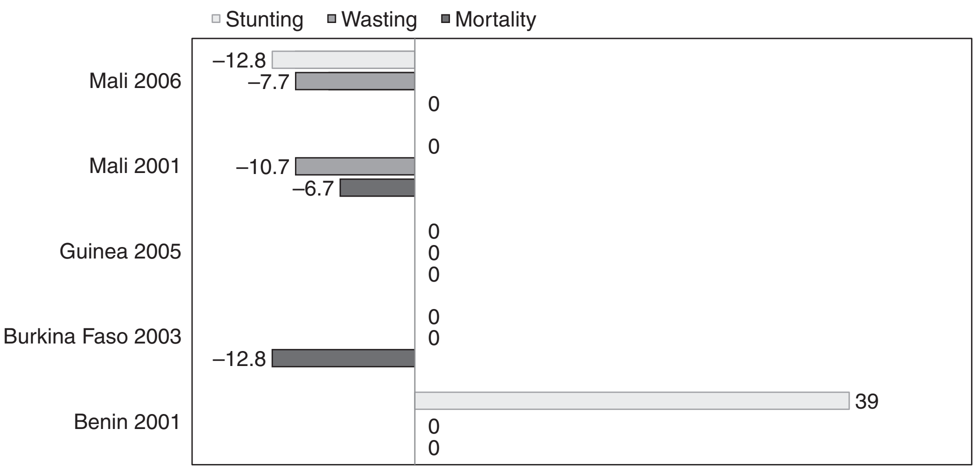

FIGURE 8.5 Summary logistic regression results: percent change in stunting, wasting and mortality of children under the age of five associated with each unit increase in NDVI (only associations significant at $p < 0.05$ are reported).

NDVI is significantly associated with a reduction in wasting in both Mali surveys (11 percent reduction in 2001 and 7 percent reduction in 2006). Aside from age, NDVI was the only other important variable in the model in Mali 2001. In Mali 2006, children whose mothers were engaged in non-agricultural employment were significantly less likely than children of agricultural workers to be wasted. Children living in households in the wealthiest quintile were also significantly less likely to be wasted in Mali 2006. In all other countries, age was the most important determinant of severe wasting (Johnson and Brown, 2013).

The impacts of environmental variability will differ depending on national and regional responses. In this analysis, we see that the two driest countries, Burkina Faso and Mali, show the strongest response to changes in NDVI. In Burkina and in Mali 2001, increased NDVI reduces the probability of mortality, and in Mali, increased NDVI is also associated with decreased odds of being severely wasted; however, Burkina Faso did not show any relationship between NDVI and wasting. These differences highlight the differences in the social, political and economic situation of the two countries (Johnson and Brown, 2013).

The results show the net effect of all the different programs, projects and activities that impact communities over time. Thus the different results seen in Mali in 2001 and in 2006 may be due to improved access to resources to support child nutrition, reduced food prices or an improved local economy that contributed significantly to household well-being. Exactly which of these contributed to the decline over time, or if the results are spurious, is unclear.

The variability across countries in the association between NDVI and the outcome variables in this analysis requires further investigation into the pathways between NDVI (and, presumably, agricultural production) and child nutritional and survival outcomes. Other areas of interest for further analysis include looking at the association between NDVI over the course of several years and women's anthropometry. The DHS dataset would also be useful for exploring issues of urban childhood nutrition and the impact of local, regional and global environmental variability and the price of food in the market (Johnson and Brown, 2013).

Summary

This chapter focused on the outcome of food insecurity in households on nutrition outcomes. Analysis of the causes of malnutrition was examined and the likely conceptual relationships between environmental dynamics and human health outcomes. Analysis was presented that provided insight into the impact of climate variability on stunting, wasting and mortality in children under five in West Africa, and the likely impact of changing ecosystem services on diet and diarrheal disease in Malawi. These studies show the complexity of the impacts of climate variability and the multiple dimensions, but do not diminish the importance of measuring food security, climate variability and local food prices.

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9

POLICY IMPLICATIONS OF PRICE DYNAMICS AND THE WAY FORWARD

Chapter objectives

This chapter will look forward, providing recommendations and policy suggestions for decision makers tasked with improving global food security. The chapter begins with discussion of the challenges for the global community in achieving food security for all and how economic modeling and information can improve the three most commonly used government policy responses to food price volatility: trade policies, cereal storage programs and social safety nets. The chapter continues with specific suggestions of how models that integrate climate variability and price information can improve policy implementation. The chapter concludes with a description of technological solutions, development initiatives and market, price and environmental information products that may reduce the food security impacts of high and variable food prices and extreme weather events.

Distribution, governance and institutions

The hypothesis of this book is that high food prices and unpredictable price changes have a significant and detrimental effect on food security outcomes, and changes in prices are an outcome of climate variability and its impact on local food production. Over the past ten years, the international price of rice, wheat and maize have nearly doubled. Food price spikes can have large and potentially irreversible impact on social welfare, including spending on health, nutrition, schooling of boys and girls, child labor, and savings (Grosh *et al.*, 2008). Maintaining adequate consumption and defending critical livelihoods in the face of rapid increases in the price of food can be enormously challenging for all except the most well off, particularly for countries whose populations already spend over half their income on food.

Trade and food marketing are central to both supplying adequate food to all and providing income for the farmers who grow it. Trade allows for food to be imported when local production is insufficient, enabling stability of supply. To make trade function, government and its civil institutions must provide essential public services such as peace, the rule of law, public research to generate new agricultural productivity, clean water, electric power and rural transport infrastructure. In developing countries where large numbers of people are food insecure, governments and civil society have only weak influence on local and national markets and food governance institutions (Paarlberg, 2002). Addressing these issues are critical for improving the functioning of local markets, since farmers need to be able to sell their surplus without their profits being consumed by transport costs, market expenses, bribes to officials and other expenses. Improving both governmental and non-governmental organization's ability to reduce marketing expenses is critical to the goal of greatly increasing the ability of farmers in food deficit areas to expand production to meet the needs of a growing population (Ihle *et al.*, 2011).

Political marginalization of poor and rural populations deepens food insecurity by delaying rural transport infrastructure and isolating farmers and consumers (Harding and Wantchekon, 2012). Better rural infrastructure would link farmers to local, national and international markets so that they can sell the goods they produce and have access to the lowest cost food available. Rural infrastructure is undeveloped in most of Africa; in some regions roads and rail infrastructure have remained unchanged for four decades. Greater leveraging regional integration and trade could generate economies of scale in production, expand markets for farmers and increase the variety of foods available for consumers. Increased integration in the international economy will mean that African producers will find a larger market for their goods and will be able to invest in producing new food products that urban consumers want (UNDP, 2012). Integration also poses risks for local communities, but the benefits are likely to outweigh risks if lower food prices result (Barrett and Bellemare, 2011; Moseley *et al.*, 2010).

Governments and policy makers can mitigate the impact of high food prices using the policy instruments mentioned above, but there are other approaches that can be taken to reduce the impact of climate variability and high food prices directly on the poor. These include policies that:

- increase food availability and food production through investment in agricultural extension, research and development for increased food production (Nin-Pratt *et al.*, 2011), irrigation systems and water availability for agriculture (You *et al.*, 2010), improved property rights and land tenure (Kepe and Tessaro, 2012), improved rural transportation infrastructure and new efficient ways to store food and transform it for improved shelf life (Sharma, 2013);
- improve food access with broad-based economic growth that increase incomes in both rural and urban areas (Headey, 2013), increase labor productivity with technology and new approaches to food production and other wage labor, provide reliable social protection and safety net programs that include food assistance for the poorest parts of the population (MacLean, 2002; Garg *et al.*, 2013);
- improve food utilization through investment in potable water, immunization programs and improved child care through breastfeeding and other health programs focused on reducing infectious disease (Dangour *et al.*, 2012), improved nutrition education and other interventions such as hand washing and sanitation facilities (Casanovas *et al.*, 2013); and
- accelerate conflict resolution and improve trade flows (Wu and Guclu, 2013), reduce transaction costs and improve farmer connectivity to regional and international markets to ensure stable access, availability and utilization to food (Nelson *et al.*, 2010).

Accomplishing these goals can improve food security in the face of environmental and economic shocks. They are enormously challenging, and are basically the development agenda for the coming decade.

Policy response to respond to food price volatility

While working to implement policies that enable development, countries also work to reduce the impact of food price volatility on their populace. These are critical for the political survival of the leadership of many food insecure countries, including India and Haiti (Timmer, 2010). Governments cannot be seen to be doing nothing when food prices double over very short periods (Poulton *et al.*, 2006). There are a number of policy responses that governments can take to deal with food price spikes and volatility. They include:

- trade policies that focus on stabilizing domestic food prices by subsidizing imports when world prices are high and tax imports when world prices are low for food importing countries and restrict exports and subsidize imports for food exporting countries (termed "countercyclical" trade policies) (Gouel, 2013);
- food storage can reduce the impact on prices by changes in the amount of food produced if supplies are released when food deficits occur and purchased by the stock holder when food surpluses occur (Gilbert, 2011);
- implementation of variable quantity social safety nets that increase support for the poorest populations during times of high food prices and reduce support during times of low prices to protect consumption by the poor (Do *et al.*, 2013).

These policies are reviewed in Christophe Gouel's 2013 World Bank report on domestic stabilization policies. Here our interest is in how observations of the impact of climate variability and local price movements can be used to improve prediction of food price movements. Each of these policy responses will be examined as to how information on weather-related production shocks and their likely impact on local food prices can improve policy implementation or provide insight that is currently lacking.

Countercyclical trade policies

Gouel (2013) describes trade policies that use import and export taxes and tariffs to change food supply in response to changing local food prices. Approaches that such policies take include import subsidies, tariffs, export controls, restrictions on food imports, marketing boards, producer subsidies and other approaches that many economists and trade policy experts do not recommend. These policies often work by harming trading partners or transferring risk to those nations forced to import food from elsewhere. Justifications for such policies include lack of reliability in the international commodity market and lack of private storage to minimize local price volatility, as well as the negative impact of price spikes on the welfare of the poorest.

National trade policies that use the tactics described above can increase the price of food in a country. Often the benefits of such policies accrue to large producers, not to consumers or smallholders. Barrett and Bellemare (2011) argue that higher prices, not volatility, matter to the food insecure. Price spikes that rapidly increase the price of food can cause civil conflict, uncertainty and lack of access to food. Once the prices are high, if they stay at a higher level it is very damaging to long-term development. High food prices damage socially important long-term investments by poor households such as education, consumption of diverse and nutritious food, and spending on individual health care (Barrett and Bellemare, 2011). Trade policies that increase the price of food through restricting trade are often regressive, transferring wealth from the poorest to the better off segments of the population (Gouel, 2013).

Unfortunately, is hard to show the impact of a trade policy on food price levels in any one country, even if it is successful in reducing price spikes. Due to imperfect implementation and multiple stressors including large external price drivers and changes in supply to the market that may be outside the control of the government, it is hard to say why food price levels are high in any particular time or location (Gouel, 2013). Thus countercyclical trade policies are becoming more, not less, common. These trade policies are not encouraged by economists and policy experts and can be damaging in the long run to food security globally (Rashid *et al.*, 2008; Anderson and Nelgen, 2012; Do *et al.*, 2013).

Trade policies could be more responsive to local changes in production if they used updated information on the growing conditions in agricultural production regions that produce tradable surpluses. Knowing about impending production deficits or surpluses within a country will help anticipate and plan for dynamic policy response. Intelligence on where imported food originates and the likely impact of weather-related production anomalies on areas outside the country will also be important. Although trade policies are effective at counteracting the impact of international price volatility and price spikes on local food prices, the simultaneous disruption of local supply during times of pressure from international prices can reduce the effectiveness of these policies (Rashid *et al.*, 2008).

The high degree of local variability in food prices from one market to the next means that although trade policies must be applied at the national level, the impact of local weather effects and accessibility to international price signals is not consistent across a country. As described in Chapter 7, markets are highly heterogeneous in their response to changes in local production and international price signals. Markets that produce surplus food are more likely to have prices that exhibit seasonal variability and be affected by local weather shocks. African countries in particular, since they have highly porous borders and weak government institutions, have difficulty implementing effective policies that reduce the transmission of price spikes across national borders (Tschirley and Jayne, 2010). More information about the likely impact of weather, the yields and potentially food prices of their regional trading partners will help these countries anticipate locally relevant changes in food supply and demand (Gouel, 2013).

To reduce the impact of food price spikes on food security, trade policies must be implemented quickly and with transparency to other actors in the market. Private traders who may store and move grain in normal years need be involved in the decision making and implementation of these policies to ensure that they work well (Porteous, 2012). The lack of trust between government actors and private actors in Southern Africa restrained the action of private traders during times of significant supply stress, causing Zambia to have three severe food price spikes between 2000 and 2008 (Tschirley and Jayne, 2010). Poor policy timing can cause increases in transaction costs and changes in informal trade flows but do not restrict trade, making it even more important for actors to know the supply situation in regions outside the borders of these countries where food comes from in times of scarcity (Anderson and Nelgen, 2012). Early and actionable information on production anomalies and their local food price consequences can make a difference in improving the timing of trade policy decisions.

If a country is using trade instruments to reduce price volatility, information on the likely supply of food several months in advance can be helpful in formulating and articulating its trade policy. This information can be useful for estimating regional food availability and the likely cost of goods from regional trading partners. It could also allow for more quantitative assessment of the likely need to go to international markets for food. Integrating price impacts of supply and demand due to weather-related drivers can be a powerful tool to garner more value from existing agricultural monitoring information.

Use of integrated price–production information can be better leveraged with information about where food is imported from during different years. During times of plenty, a country may have different trading relationships with its neighbors from during times of scarcity. Research presented in this book has showed that trade flows can change dramatically across a dense network of markets due to weather-related production shocks as well as other external shocks (Brown *et al.*, 2012; Essam, 2013). Improved trade information that can provide intelligence on the movement of food will allow for the development of strategic information that can improve the implementation and impact of trade policies.

Food storage policies

Although the purchase and storage of grain in good years and subsequent release in bad years can be an effective strategy for ensuring a stable supply of food, it is also very expensive. The cost and logistical complexity of grain storage systems implemented by governments has been discussed by many, with the result that countries now receive policy guidance to use other means to reduce price volatility (Miranda and Helmberger, 2012; World Bank, 2012; Williams and Wright, 1991). Storage can be effective in reducing the impact of very high food price changes on poor populations, increasing welfare of the community, but it tends to crowd out private food traders who may store food for profit, affecting the functioning of commodity markets that are already thin for other reasons (Gouel, 2013). Despite this, many countries have retained at least a partial food storage system and use it to increase public welfare. Although India has managed to prevent any major food crises over the past 40 years, its storage policy could be improved with clearer release rules and a stronger response to protect the poor in bad years (Busu, 2010).

Explicit information on what food is being produced where, and linking information on the impact of significant anomalies on food prices can be integrated with storage policies. A finding of this book is that local food production and local food prices vary across a country, with impacts on food security that can be intense locally. Dynamically changing purchasing power due to demand shocks and weather events can be linked to observations of agricultural performance and be very different from one region to another in a country (Sen, 1981; Alderman and Haque, 2006). Government-run storage systems can be changed to respond to these local variations in ways that national trade policies cannot. Even with such changes, storage systems will be inherently expensive and logistically challenging.

Public social safety nets

Grosh *et al.* (2008) state that rising food prices harm public welfare and development in four ways: by increasing poverty, worsening education outcomes, reducing the utilization of education and health services, and depleting the productive assets of the poor. Since the ultimate objective of many governments' food policies is to reduce or remove these impacts on the poor, not necessarily to reduce food price volatility per se, then social safety nets may be an effective alternative to national-scale trade policies or large-scale storage schemes. The focus of safety net programs is to improve people's capacity to deal with large food price movements, not to change the actual price of food directly. They can complement market-based policies and be part of a broader intervention that can have very positive impact on welfare and reduce food insecurity directly.

Unfortunately, safety net programs are difficult to implement, since they require increasing spending during bad years and reducing spending during good years. For the program to protect consumption during food price spikes, benefits would need to be extended to new households pushed into poverty when prices are high and then removing these families from the benefit roles after prices decline. These programs can protect both against shocks to income due to production declines as well as increases in expenditures due to increasing food prices. Most safety net programs were not designed to serve this insurance function, however, as they are often used to boost development and permanently raise the incomes of the poorest segment of the population. Thus most safety net programs move only slowly, whereas food prices can double in a matter of months. These programs are also very difficult to scale back after expansion.

In addition to administrative challenges in ensuring responsiveness, paying for large increases in assistance during times of high prices requires flexible financing on the part of governments and institutions (Alderman and Haque, 2006). Grosh *et al.* (2008) state that the reliance on food (and fuel) subsidies put the governments at significant fiscal risk. Between 2005 and 2008, the food subsidy bill in Morocco, Tunisia and Egypt grew 0.5 to 1.5 percent of the gross domestic product. Without effective targeting, social safety programs can take up an increasing part of the national budget while simultaneously increasing local demand for food during times of scarcity (Do *et al.*, 2013). Local food prices may increase due to this increase in demand unless supplies can be increased.

The models and concepts presented in this book could be useful in improving the targeting of the populations needing assistance, if it were combined with information on livelihood and vulnerability. Unlike trade policies that tend to over-react to price spikes through closures of borders, accumulating stocks and banning exports during times of crisis, flexible social safety nets are considered an effective policy response to high food prices. High quality information about the interaction between local production anomalies due to climate shocks and high food prices can improve targeting of such systems.

Technical responses to food security challenges

The next sections focus on practical ways that food price and climate variability modeling can be integrated into government programs and food security analysis. These include improved information on food prices, small farmer insurance programs and public investment in higher yielding crop varieties.

Food price database systems for improved analysis

Although there is a great need for more information about the cost of food in both rural and urban markets in the developing world, rapidly updated, high frequency (monthly and weekly) food price information systems remain in their infancy. The data collected by existing systems are very sparse and the time series begins less than a decade ago. Few food information systems have adequate observations outside capital and regional cities. Small cities and towns are vulnerable to interannual variability of prices and the impact of changes in food production, but these communities have the least amount of data for analysis (Brown et al., 2009).

The international community has a good grasp on internationally traded agricultural commodities. They monitor various attributes of traded commodities (area harvested, production, consumption, export/import volumes, traded prices, etc.). However, these systems provide little or no information on locally grown crops and regional price dynamics. The FAO's Global Information and Early Warning Systems (GIEWS) worked together with USAID and other international organizations to create a database of basic food prices. The GIEWS Food Price Data and Analysis Tool was released in March 2009 and was supported by the FAO Initiative on Soaring Food Prices (ISFP). The food price tool consolidates consistently updated food price information and allows open access to the information. Another organization working on food prices and trade is the Agricultural Market Information System (AMIS), a Group of Twenty Finance Ministers and Central Bank Governors (also known as the G-20, which are the 20 major economies (19 countries plus the European Union)). The focus of AMIS is to enhance food market transparency and encourage coordination of policy action in response to market uncertainty. Although AMIS only focuses on wheat, maize, rice and soybeans, it captures a large share of global production, consumption and trade volumes of the targeted crops, typically in the range of 80–90 percent. Although this system gives a good idea of the internationally traded commodities, it does little for the unprocessed coarse grains typically consumed by the food insecure, poor populations of the developing world. In the 15 countries in Africa that are landlocked, the need for locally collected price information is even more pressing. Without information on price dynamics of these untraded goods, food security and market functioning in rural areas of the continent cannot be appropriately assessed.

Currently utilized data collection tasks/methods are extremely expensive and, therefore, rarely cover rural areas. Market information systems need to be extended to the locally grown and consumed commodities and obtain observations across many communities. Nearly 75 percent of the world's population now either has a mobile device or has a family member who does. With that in mind, institutions need to create a fundamental shift in how price information is collected. Local participation will be critical for the overall success of this method and, at same time, beneficial to all parties involved. If market conditions can be created using cell phones that provide employment opportunities to young people, women and other disadvantaged groups, then far more price data can be gathered on a wide variety of markets on locally consumed crops. If institutions can provide financial assistance through the use of different options (monthly phone charge coverage, airtime cards, etc.), we can gather data much more cost effectively than paying individuals directly. With more observations in each country, these institutions can determine the local price dynamics that control access to food for millions of rural residents.

This approach is currently utilized in Ethiopia, Kenya and Zambia under the EU Commission project. Gathering data since the spring of 2013, the project has the potential to expand greatly its impact by moving to gathering data via cell phones. Further analysis of these collected price indicators could be extremely valuable to areas outside agriculture and food security. With a number of ongoing conflicts in Africa, it is very important to understand the dynamics of food prices prior, during and post conflict conditions. An effort to collect food price information should provide insight into overall stability in the 19 fragile states in the region. As a pilot exercise, this data collection approach should be launched in a few stable and a few fragile states in Africa.

Drought monitoring systems to anticipate the impacts of climate variability

Information about the weather in the upcoming growing season is a critical and little exploited way to reduce the impact of climate variability on agriculture. As described in Chapter 3, climate variability refers to short-term (daily, seasonal, annual, interannual, several years) variations in climate. As food production is increasingly affected by weather shocks, monitoring and mounting an effective response to extreme events will become more important to ensure a reliable and consistent food supply. Food access will become increasingly affected by climate variability in remote areas that have limited access to other markets.

Iizumi *et al.* (2013) presents a global assessment of the reliability of crop failure retrospective analysis for major crops at two lead times derived by linking ensemble seasonal climatic forecasts with statistical crop models. Pre-season yield predictions employ climatic forecasts and have lead times of approximately three to five months for providing information regarding variations in yields for the coming cropping season. Within-season yield predictions use climatic forecasts with lead times of one to three months. Pre-season predictions can be of value to national governments and commercial concerns, complemented by subsequent updates from within-season predictions. The latter incorporate information from meteorological networks and satellite data for the upcoming period of reproductive growth (Iizumi *et al.*, 2013).

Moderate-to-marked yield loss over a substantial percentage (26–33 percent) of the harvested area of these crops could reliably be predictable if climatic forecasts are near perfect. However, only rice and wheat production are reliably predictable at three months before the harvest using within-season forecasts. The reliabilities of estimates varied substantially by crop: rice and wheat yields were the most predictable, followed by soybean and maize. The reasons for variation in the reliability of the estimates are the differences in crop sensitivity to the climate and the technology used by the crop-producing regions (Iizumi *et al.*, 2013). The findings reveal that the use of seasonal climatic forecasts to predict crop failures will be useful for monitoring global food production and will encourage the adaptation of food systems to climatic extremes.

Hansen *et al.* (2011) argue that in some locations, seasonal forecasts can be demonstrated to have accuracy in predicting the upcoming season. The effective management of climate risk requires both information and the ability to respond or mechanisms of response to extreme events. The ability to anticipate climate fluctuations and their impact on agriculture months in advance should, in principle, enable several opportunities to manage risk. The authors point out that these opportunities can be exploited, but only within an enabling environment that will provide farmers with the opportunities to adopt improved technology, intensify production, replenish soil nutrients and invest in more profitable enterprises when conditions are favorable; and to protect more effectively families and farms against the long-term consequences of adverse extremes (Hansen *et al.*, 2011).

Early identification of extreme events such as drought and unusually wet conditions is important for early detection of widespread food production deficits. Poor rainfall accumulations can be identified early in the season and can be a critical mid-season indicator of likely significant reductions in final seasonal totals (Husak *et al.*, 2013). Earlier warning of food production problems will enable organizations such as WFP and FEWS NET to monitor and identify likely food security and food access problems that these production declines may cause. Improvements in rainfall and temperature-based moisture datasets in the next few years will enhance our ability to remotely estimate poor growing conditions that cause crop failure.

The relatively short record of satellite rainfall estimates also presents a limitation to understanding the range of drought events required for adaptation to these events. Given that the impacts of drought on regional food production are a function of the severity and spatial extent of dryness, there exists a need to understand better the probability of dry events in a way that captures not only the likelihood of drought at a single location but the likelihood of regions experiencing dry conditions. Husak *et al.* (2013) described a method to create seasonal rainfall scenarios from existing satellite rainfall estimates to understand better the likelihood of extreme events. Rainfall simulations can better capture the range and likelihood of growing conditions in areas where the short satellite estimates prove inadequate on their own. The approach also captures rainfall conditions in such a way as to enable the simulation of crop growing intervals, rather than calendar intervals, and to play those conditions out for the remainder of the season to give a sense of the remaining uncertainty in moisture conditions. Providing this information to decision makers can assist in determining the timing and amount of aid needed to mitigate food shortages resulting from poor rainfall performance (Husak *et al.*, 2013).

Unfortunately, there are constraints to using weather predictions related to legitimacy, salience, access, understanding and capacity to respond (Husak *et al.*, 2013). Even in developed country agricultural systems where resources are far more abundant, logistical constraints restrict the optimal timing of planting to just a few days at the beginning of the season. Few farmers can decide to move from corn to millet on the basis of a forecast, due to the enormously different economic value, required growing conditions, equipment, expertise and seed availability of the two crops. Once the crop is in the ground little can be done to change the progress of the crop's response to growing conditions.

Research is being done that will improve our understanding of what a good forecast is, how forecasts could be used, and on ways to incorporate observations with forecasts to enable a comprehensive description of potential climate impacts on agriculture in a particular place. These location-based probabilities can be used to develop risk management tools priced and sized according to the likelihood of a yield-reducing drought.

Index insurance to reduce the impact of weather shocks on income

Information on weather and climate can enable the implementation of agriculture insurance across large areas to provide basic weather-risk and financial support to farmers who are vulnerable to food insecurity as a result of weather shocks (Helmuth *et al.*, 2009). Index or parametric insurance providing an indemnity payout that depends on exceeding a threshold variable such as water level (for floods) or consecutive days without rain (for droughts) could fill that gap. These programs provide insurance against income drop, but do not help protect consumption. There are a number of insurance companies and non-profit development organizations working to develop index insurance for smallholder farmers across the developing world. Index insurance can facilitate the availability of credit and enable widespread increases in the use of fertilizers and improved seeds.

There are several recent index insurance projects for low-income developing countries that are growing dramatically, in spite of concern that index insurance demand is not strong (Banerjee and Duflo, 2011; Cole *et al.*, 2009; Hazell *et al.*, 2010; Giné and Yang, 2009). Even where there are programs available, there is low uptake by the community because of a lack of trust in institutions and governments. Given their growth, the potential for both undesirable and unintended negative consequences are large due to the number of index insurance projects exploding from only a few hundred clients to tens of thousands of clients in only two to three years (Syngenta, 2011; Oxfam, 2011). In India, subsidized index insurance has been adopted for the first time by many millions of farmers in less than ten years (Clarke *et al.*, 2012). Since projects like these have exhibited such dramatic growth it is critical to get them right.

Index insurance is not a gift or a subsidy, but a way in which a person/farmer can pay a small amount in good years and receive protection in bad years. Typically, in existing pilot projects, premiums have been designed to provide one year of insurance coverage only, and are not cumulative. Farmers make the decision each year as to whether or not they wish to re-purchase insurance for the coming growing season. If yes, then they can pay the premium and receive coverage for that specific year. The use of a parametric trigger or index has particular advantages in a developing country context, as it reduces or eliminates economic constraints such as moral hazard or an incentive to cheat and high transaction costs that reduce the viability of traditional indemnity-based agricultural insurance in these areas (Brown *et al.*, 2011). However, a trade-off with index insurance is an issue referred to as "basis risk." Basis risk refers to the potential that an index will not always correspond precisely to a farmer's actual crop loss experience, due to imperfections in the correlation of the index to actual crop production. The lower the correlation of a particular index to actual crop production, the higher the basis risk and the greater the chance that a farmer will not receive a payment in all bad years.

Reducing basis risk is a key component of responsible index design, and a key constraint in the effective scaling of index insurance programs. By assessing the effectiveness of multiple sources of information for long-term drought recurrence in Africa, and an improved relationship between this information to actual crop loss, these projects will help to develop better remote-sensing-based datasets and drought records which will reduce basis risk in index insurance products, and help with the more effective, rapid and responsible scaling of ongoing and future pilot projects. Such improved remote sensing datasets can also help to speed scaling by reducing the need for costly, time-consuming visits by project staff to verify indices and ground-truth satellite measurements to crop loss in advance of contract design. The criteria for an effective trigger for payout of insurance need to include the following:

- accuracy – demonstrated relationship with the insured commodity or agricultural yield;
- timeliness – ability to provide the information soon after its acquisition without delay (hours to days, not weeks to months);
- availability of data to everyone in the community who would like to use it;
- the cost of obtaining, processing and providing data;
- sustainability of the data product – should not be based on an experimental dataset without planned replacement;
- comprehensibility – the index should be explainable to a multi-disciplinary community and the consumers of the insurance products;
- suitability – operational capability of the product and demonstrated ability to distribute the data to a broad community.

Index insurance cannot bring the needed widespread improvements in yields and ultimately food production without a scalable, accurate, weather-related index that can be used to estimate the probability that a region will experience a drought and to trigger payouts across multiple regions and agro-ecosystems. Currently, weather insurance programs are based on a single remote sensing dataset, such as the NOAA Rainfall Estimate product, that has not been validated for the agricultural regions in which it is working (Helmuth *et al.*, 2009). Reliable and accurate remote sensing observations can ensure that index insurance is based on scalable datasets, to enable their implementation across large areas without weather stations. Using satellite-derived information on moisture availability from satellites promises to enable a much wider expansion of index insurance beyond Ethiopia and Kenya where the programs have developed (Helmuth *et al.*, 2009).

Estimates of moisture conditions can inform, validate and assist in pricing of index insurance. The probability of a drought will be estimated using precipitation and evapotranspiration information for each community, and this information will be integrated into index insurance pilots. There are currently nearly 40 pilot projects introducing index insurance to over a dozen developing countries (Hazell *et al.*, 2010). The economists at Columbia University's International Research Institute for Climate and Society (IRI) have been working to scale-up some of these pilot projects to allow for implementation in many more communities at once (e.g., see Oxfam, 2011). There is a new pilot project in Senegal that will help develop replicable methodology using previously successful projects that are sustainable and have the potential to expand into new areas much more rapidly and efficiently than previous pilots.

Improving the characterization of the nature, magnitude and probability of drought return frequency for Africa, and by helping to identify trends in the occurrence of these events, remote sensing datasets can provide the quantitative underpinnings for improved, more reliable index insurance pricing (Brown *et al.*, 2011). The final price (or premium) of an index insurance product typically reflects the cost of both: (1) insurance protection for climate risk; and (2) insurance protection for information uncertainties about climate risks. When insurance providers lack sufficient or reliable climate data, they are unable to accurately price their products, forcing them to price contracts conservatively (meaning higher premiums) to ensure that they can be honored. The longer climate records and better characterizations of drought recurrence have the potential to improve the accuracy of index insurance pricing and therefore improve access to, and the sustainability of, climate insurance for poor farmers.

Climate data for index insurance

Climate data that are useful for triggering index insurance must be highly correlated to actual yields in farmers' fields. In order to verify that a particular environmental or satellite data index can capture accurately production, we need to have accurate, high resolution and crop specific yield information. Yield information can be difficult to collect and is often not transferable across countries or regions due to differences in the type of crop or the markets for the food produced. This kind of information must be geolocated to a specific location and have explicit information about the area where the production occurred. For many countries that are food insecure, calculating yield and even tracking the total amount of food produce is enormously challenging given the large number of very small producers, many of whom never market their produce. They grow food and consume it themselves or sell only to their neighbors without going to a market. Thus local goods that are neither recorded nor taxed are very hard to track.

Plate 23 shows a communal field of the local grain, teff, in Adi Ha, Tigray region, Ethiopia. The field, large and irregular, contrasts nicely with the irrigated orchard and vegetable fields that stand out as being far greener than the hay-colored teff field. Identifying this region as a field and relating the variability of teff production to growing conditions is the challenge of creating a suitable index for insurance contracts. Productivity comparisons of modeled versus observed production must be done on an annual basis, thus many years of observations are needed.

Figure 9.1 shows the flow of information in an index insurance project, and the various inputs needed to develop and implement an insurance contract. Information about the probability of a drought is incorporated into the contract design, as well as used as an input into the trigger value written into the agreement. Moving away from the necessity of having households be near to a meteorological station will greatly increase the number of households that can participate in index insurance programs. Improved assessment of the relationship between temperature, precipitation, vegetation and actual production will reduce the risk in writing the contracts as well, helping to drive down the cost of the program in the long term.

Improved crop varieties and fertilizer to improve production in good years

In order to take advantage of improved models that estimate future growing conditions, farmers need to have improved varieties of the crops they are used to growing and that have a local market for the product after harvest. Agricultural development programs are working to provide new crop varieties and hybrid varieties that can have much higher yields in years with good growing conditions. There are three kinds of varieties of seeds:

- Open pollinated crop varieties with widespread use that pollinate and reproduce naturally (either through self- or cross-pollination), and whose seed can be saved, unlike to hybrid seed.
- Local varieties that have been developed by farmers and are grown by farmers without any formal plant breeding
- Hybrid seeds that are produced by crossing two or more separate in-bred lines. Hybrid varieties typically produce high yields the first year, but the yield drops if recycled for a second year. These are commercially available, high yielding seeds that have new varieties introduced every year by companies such as Monsanto and Bayer.

Plant breeding has increased the harvestable portion of cereal crops from 30 percent in the 1960s to about 50 percent for modern hybrid crops (Bindraban and Rabbinge, 2012). These improvements make up approximately half of the total increase in yields. USAID is funding new hybrid varieties for commonly grown tropical crops such as okra, maize, soybean, cowpea, tomato, upland rice, sorghum, millet, eggplant and peppers. Once the varieties have been developed, then a wide variety of extension services and marketing activities must happen for farmers in remote areas to get access to them. Demonstrations of these new seeds, as well as ensuring that they work as well in the field as expected, require engagement of farmers and the use of "experimental farms." Extensive institutional support is required that

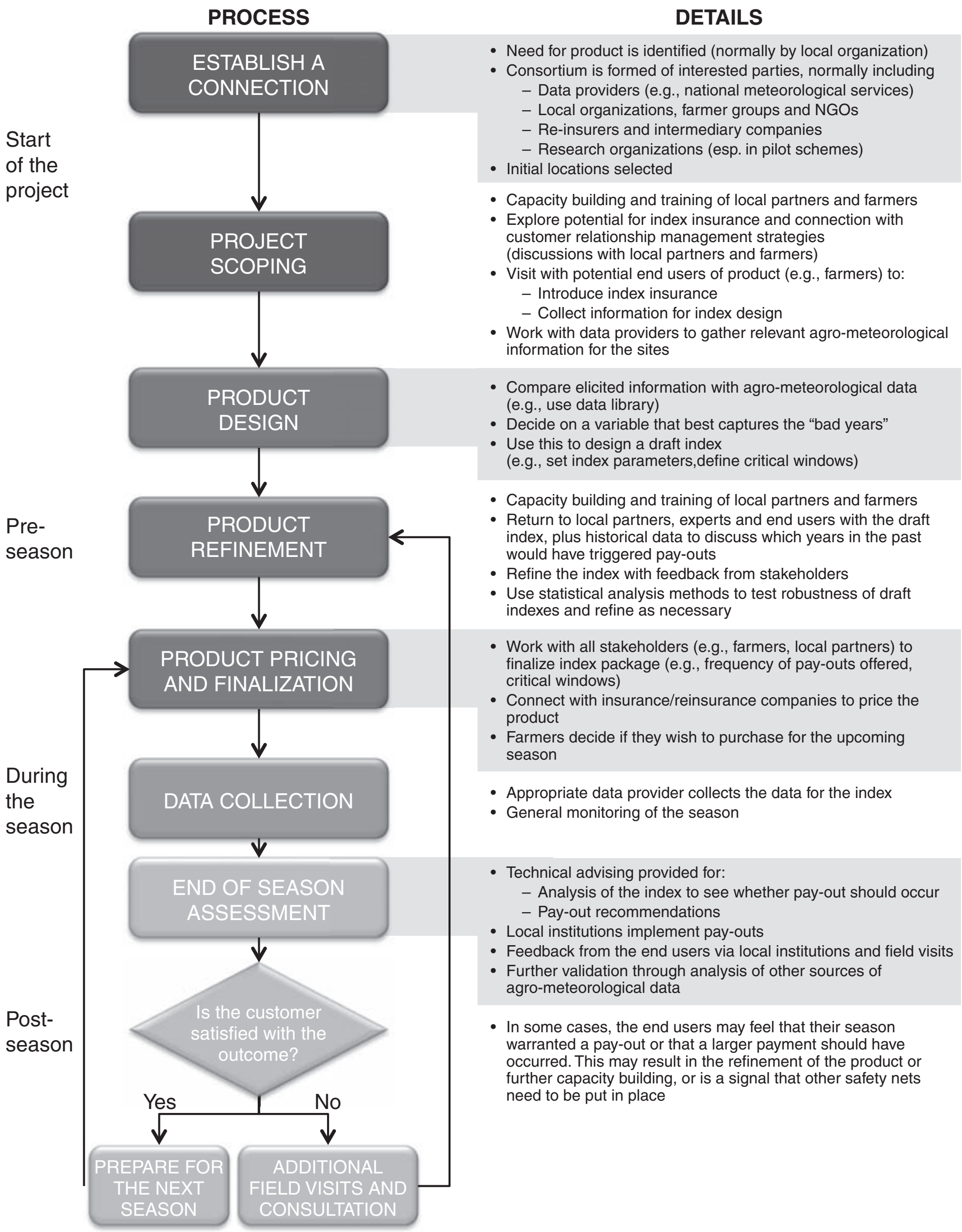

FIGURE 9.1 Flow of information in an index insurance product design (Source: Dan Osgood and Helen Greatrex, Columbia University).

facilitates the effective distribution and management of new crop varieties. Making these work, however, is very challenging.

To extend improved seeds in developing countries, researchers need to produce quality seeds sustainably, which really requires a commercial farming environment that is lacking in food insecure areas that rely primarily on subsistence agriculture. Even in these areas, however, there is a significant community of agricultural workers, researchers and the institutions that are aiming to promote income-generating prospects for traditionally subsistence crops. The focus of these activities is to enhance the prospects of establishing a sustainable and effective seed industry that will serve the needs of growers and lead to significant improvements in the efficiency of production.

An example of the agricultural development projects is the work of the Consultative Group on International Agricultural Research, that focusses mainly on cassava in East Africa. The organization uses a value chain approach to improve the productivity and commercial value of cassava. In practice, this means developing and promoting cassava-based products (such as commercially sold chips, high quality cassava flour, starch and others), improving the efficiency of marketing and markets for these products, and address the major pest and disease constraints. The group simultaneously establishes virus-free, high yielding stocks of planting material of newly released and farmer-preferred varieties, and works with small-scale cassava entrepreneurs to set up seed production and distribution businesses. As farmers get improved commercial opportunities for their cassava crops and processed products, so the potential for them to access and purchase improved seeds (and other inputs) should increase. There is much promise for major development along these lines in the next decade or so without having to resort to crop modification using genetic engineering, other than the usual conventional breeding that continues to deliver successful outcomes for increased productivity, drought tolerance and pest/disease resistance.

Studies such as that by Hamukwala *et al.* (2010) have showed that in East Africa, yields have been stagnant at about 0.5 tons per hectare for over 20 years. According to their study, average seed replacement rate in Zambia was 13.7 years compared to the three-year rate recommended in the area. Seed replacement rate is the percentage of area sown out of total area of crop planted in the season by using certified/quality seeds instead of farm saved seed. This means that the last time farmers in Zambia purchased commercially produced, high yielding hybrids was in the late 1990s. To drastically improve yields in areas with low productivity, new varieties will need to be used, as well as appropriate levels of fertilizer, in particular phosphate.

Fertilizer includes macro- and micronutrients required by plants to grow and produce grain at the highest possible rates. Inorganic fertilizer typically provides the following nutrients in varying proportions, depending on the soil type where the crop is grown:

- six macronutrients: nitrogen, phosphorus, potassium, calcium, magnesium and sulfur;
- eight micronutrients: boron, chlorine, copper, iron, manganese, molybdenum, zinc and nickel.

Yields in the United States and the United Kingdom tend to be 40 to 60 percent attributable to fertilizer, and according to Stewart *et al.* (2005), these percentages should be much higher in the tropics given the relatively low organic content of tropical soils. Calibrated budgets for nitrogen, phosphorus and potassium indicate that commercial fertilizer makes up the majority of the nutrients required to sustain yields in the United States (Stewart *et al.*, 2005). Although tropical soils have very different sensitivities to high nitrogen levels, it is clear that higher rates of fertilization could greatly increase productivity without requiring a transformation of the agriculture sector.

Low levels of fertilization and other inputs such as herbicides and pesticides characterize the subsistence agriculture sector in the developing world. Open pollination varieties, combined with very low nutrient levels, means that the low yields seen over the past five decades are actually declining. Soils in sub-Saharan Africa are being depleted at annual rates of 22 kilograms per hectare (kg/ha) for nitrogen, 2.5 kg/ha for phosphorus and 15 kg/ha of potassium (Smaling *et al.*, 1997). These declining soil fertility rates are resulting in declining per capita food production, as well as other trends such as increasing populations and reductions in rainfall in key agricultural areas (Nelson *et al.*, 2010). Thus a key aspect of food production increases needs to be increasing the accessibility of high yielding crop varieties and, most importantly, fertilizers and other agricultural inputs that will help small farmers increase food production in good weather years, and reduce vulnerability to crop failure in bad years.

Invest in marketing and food systems for climate resilient crops

Food systems need better food markets and transportation infrastructure, which will enable the marketing and sale of agricultural inputs to farmers in poor and remote areas of developing countries. Although it is easy to say that climate change and climate variability should be taken into account when choosing what crop to plant, it is far harder to create the appropriate institutional, marketing and demand infrastructure required to move from one crop to another (Brown and Funk, 2008). There are several aspects to this problem that can improve the ability of smallholder farmers to be less vulnerable to weather shocks and to reductions in access to food. These are:

- improve transportation infrastructure to increase connectivity between farmers and markets;
- increase the product differentiation of smallholder farmers so that they can compete more effectively in urban markets, so that they can be positioned higher on the value chain; and
- increase the productivity of each field and each farmer's enterprise so that more food and more income are available in regions with high population growth rates and low income.

The impact of steady reductions in agricultural development in countries like Zambia are stagnating yields and reductions in per capita food production (Funk and Brown, 2009). These issues highlight the difficulties in transforming the agriculture sector by incorporating single-sector fixes such as new seed varieties without also providing extensive new ways to move agricultural inputs into isolated regions, strengthen and reduce the cost of transportation, and developing strong and consistent demand for the new agricultural products. The entire value chain must be transformed if more productive farms are to succeed and raise the living standard of its participants.

Because many low-income countries rely upon agriculture as the main source of employment, expansion of per capita agricultural production will, it is often thought, reduce poverty rates and improve food security. But the most food insecure people in a region are also the poorest segment of the agriculture sector. These people have the least access to resources and the poorest ability to access markets and increase profits even when there is opportunity to do so. Significantly increasing productivity for smallholders may result in raising the living standards of those who have the most resources without reducing overall food insecurity. Few smallholders will be able to accumulate enough expertise, connections and resources to profit from a transforming agricultural system. Far more likely is the failure of the poorest smallholders with a significant migration into marginal urban areas to take on other livelihood strategies. This trend has already been seen in many rapidly developing countries, such as China (Qin, 2010).

Agricultural and economic development

Development and modernization includes a transformation of the rural economy, as well as increasing the productivity of the agriculture sector through industrialization. It may be that this industrialization will include the conversion or abandonment of smallholder farms as farms aggregate into larger, more efficient enterprises that can compete in the international commodity market. Whether this transformation will occur or even that it should occur in remote regions where food security is currently a problem is very unclear, given the enormous challenges of governance, population density, education, transportation and the need for significant capital investment.

The vision of agricultural development is often highly contested, where some feel that there is only a need for increased investment to increase agricultural productivity and to create jobs for poor populations in rural areas of Africa and South Asia. Jeffery Sachs, the founder of the Millennium Villages Project, has focused on geography as the cause of poverty – location, climate and environmental conditions – without regard to governance, history or culture (Rosen, 2013). Although Sachs has done a lot to keep development on the international agenda, he does not focus on institutions or political transformation, that are essential to ensure continuous and sustained investment required to reduce poverty and improve living conditions for both rural and urban populations. Setting aside the broader and extremely complicated issues of economic development, there are some examples of what possible new technological and information products can be brought to bear on improving agricultural productivity, reducing vulnerability of the poor to problems of food access and improving the government's ability to respond when things go wrong.

Approaches to improve market functioning that have been mentioned in the literature include:

- Reduce direct involvement of governments in food markets. Intervention increases the unpredictable behavior of markets and reduces the response of traders to arbitrage opportunities (Minot, 2012).
- Increase the availability of credit for agricultural inputs such as improved seed varieties, fertilizer and pesticides, and strengthen financial institutions that provide consistent credit markets (Kherallah *et al.*, 2000a).
- Develop a legal structure for market transactions. Although enormously expensive to implement, in the long term increased clarity in property rights, contract enforcement, ensuring market conduct and establishing rules of market conduct will reduce risk for all market participants (Fafchamps, 2004).

- Increase investment in transportation infrastructure and maintenance to reduce isolation of productive rural regions to urban markets (Garg *et al.*, 2013; Dillon and Barrett, 2013).
- Increase investment in agricultural institutions to ensure appropriate extension of scientific advances and improved agronomic practices tuned to the local market opportunities and agroecosystems (Lofchie, 1987).
- Promote effective governance of the state capacity to monitor market development, to enable a better understanding of price transmission and market functioning (Brown *et al.*, 2012).
- Encourage investment in cash crops for smallholder agriculturalists to meet the needs of expanding urban areas (Woodward, 1995; Moseley, 2010; Moseley *et al.*, 2010).
- Focus assistance and extension services to the poorest communities who are most food insecure, to improve the resilience of their livelihood approach (Reardon and Taylor, 1996).
- Institute sustainable and appropriate macro-economic policies that reduce the negative impact of exchange rates and protective industrial policies on the agriculture sector (Kherallah *et al.*, 2000b).

Development strategies to improve food access

For over a decade, it has been clear that food security is not about food production. In economies where agriculture is a dominant livelihood, increasing farm incomes so that households can afford to purchase food when they experience decreases in production is an important objective. These farmers also need to supply enough surplus food for the nearby urban areas that are rapidly increasing in size. Raising incomes require development across many sectors, including transportation, rule of law, market efficiency, agricultural technology, institutional support and many others. Thus in order to achieve food security, it is necessary to:

- ensure sufficient locally accessible food production;
- improve local livelihood options to increase local incomes;
- increased institutional strength to increase technology transfer to make agriculture more efficient;
- enable access to global markets for food for sale of surpluses and purchase of needed food in times of low production.

Ultimately, it will depend on the private sector to meet the needs of the agricultural community, since external development funds are so difficult to obtain and hard to focus on the need of the local community (Brown, 2006). Providing enough economic growth needed to boost the incomes of the food insecure will ultimately be the responsibility of the people themselves. The lesson of the past 30 years is stark; engagement with the private sector, increasing institutional involvement and integrity, and improving development outcomes, and hence food security outcomes is necessary to move forward.

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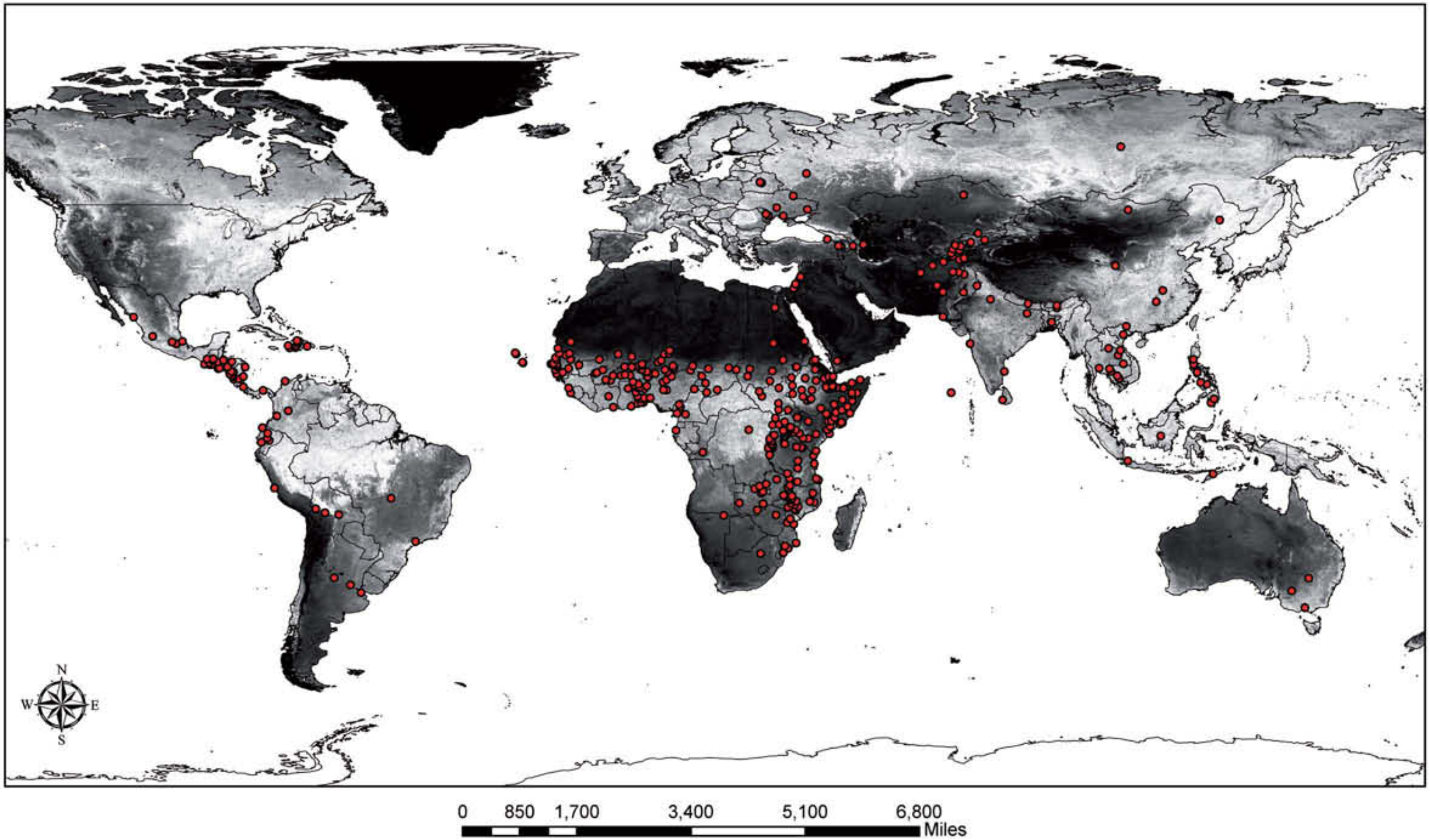


PLATE 1 Locations with regularly updated food price data, derived from the UN Global Information Early Warning System and the USAID's Famine Early Warning Systems Network price datasets (source: created by Mark Carroll).

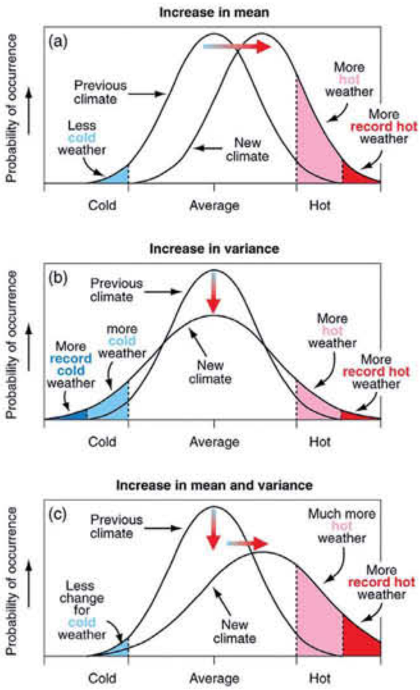


PLATE 2 Schematic showing the effect on extreme temperatures when (a) the mean temperature increases, (b) the variance increases and (c) when both the mean and variance increase for a normal distribution of temperature (source: Figure 2.32 from the 2007 IPCC report (Meehl, 2007), used with permission).

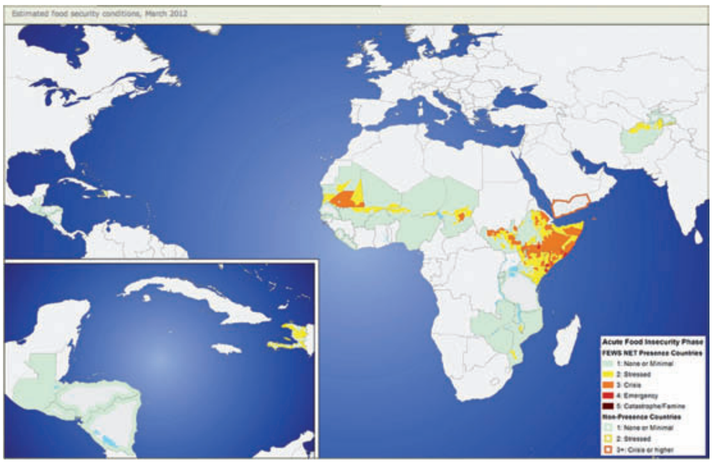


PLATE 3 Map of FEWS NET countries as of 2012.

Note

Countries with green or red-orange colors have country offices. Countries with colored outlines have FEWS NET reporting but do not have local offices. Note the sub-national representation of food security situations, enabling a nuanced and more accurate view of the local food security situation in those areas.

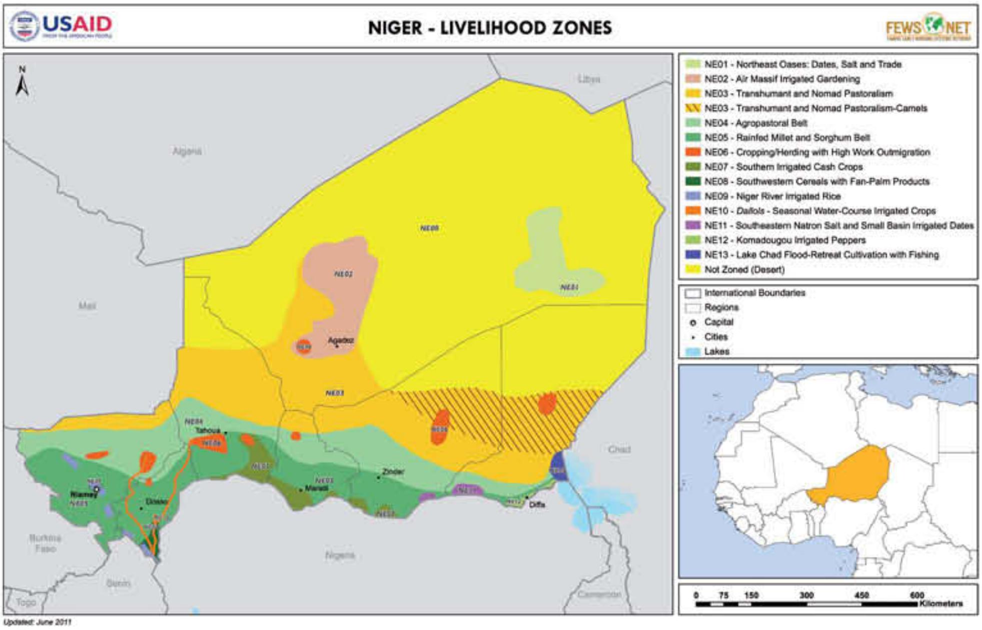


PLATE 4 Niger livelihood zones (source: derived from FEWS NET Niger livelihood zoning document, 2011).

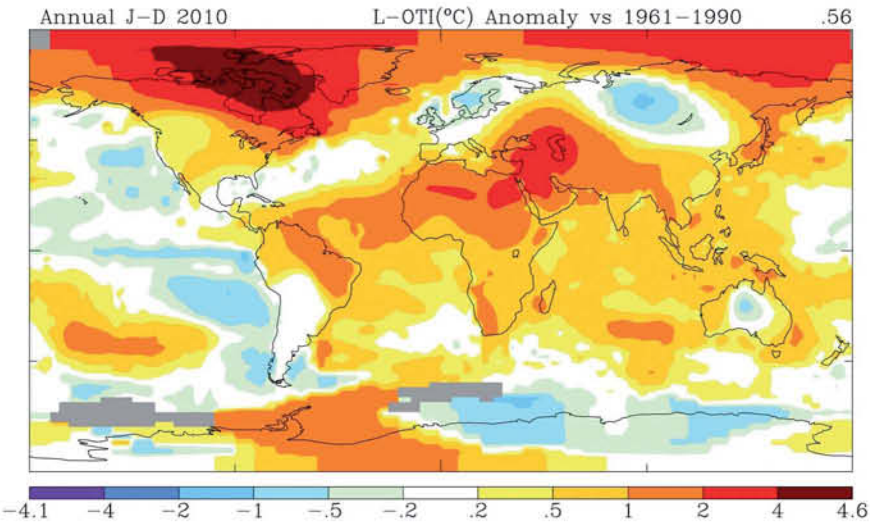


PLATE 5 Global instrumental temperature record for the past 129 years, departure from 1951–80 baseline of 14.0°C (source: derived from the NASA Goddard Institute for Space Studies online plotting tool using data from Hansen *et al.*, 2006).

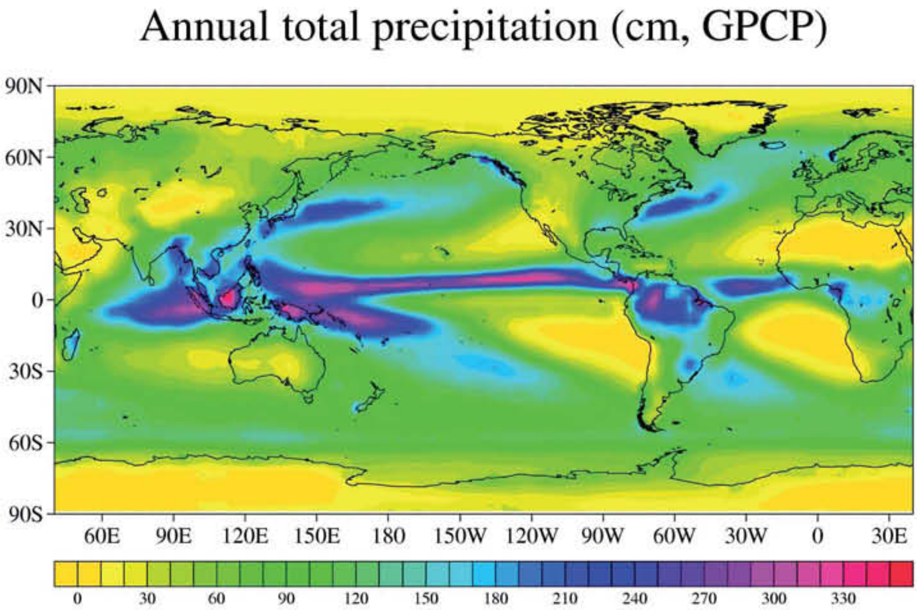


PLATE 6 The total annual precipitation in centimeters from 1988–2004 derived from version 2.2 GPCP data (Adler *et al.*, 2003) (source: data from NOAA Earth System Research Laboratory online plotting tool).

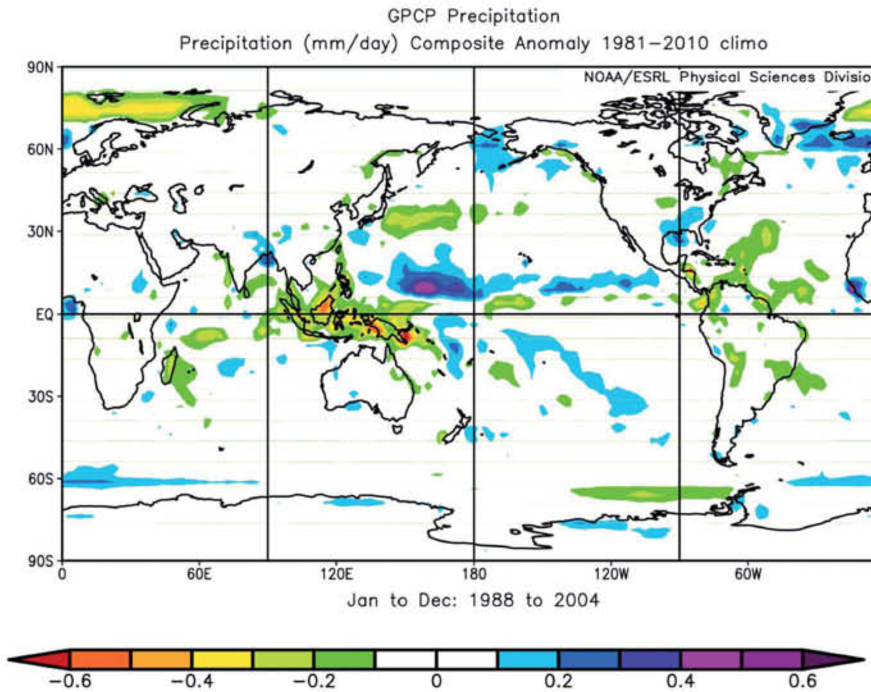
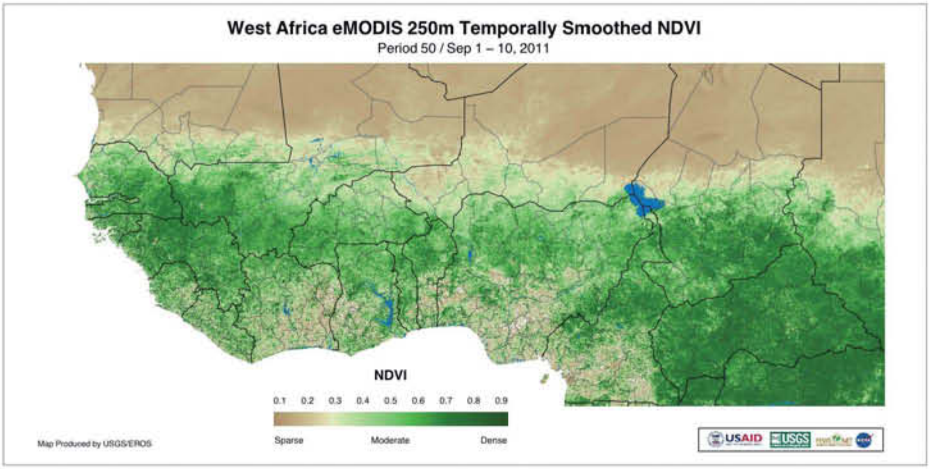


PLATE 7 GPCP annual precipitation anomaly for 2010 from the period 1988–2004 given in mm/day averaged over the year (source: data from NOAA Earth System Research Laboratory online plotting tool).

Note

The anomalies over the ocean are far stronger than those over the land, but in general the trend is weak due to the short period of record and the highly variable character of rainfall (Adler *et al.*, 2003).



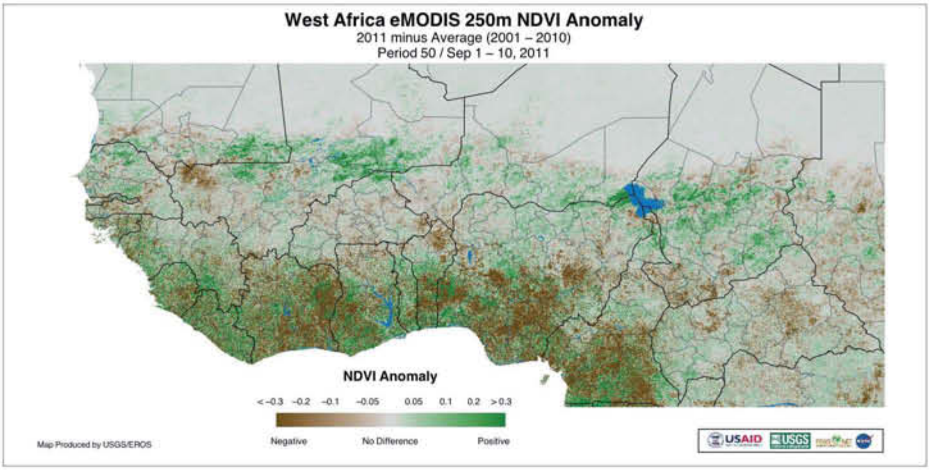


PLATE 8 Average (A) and anomaly (B) NDVI for West Africa using MODIS data for September 1–10, 2010 (A) compared to the 2001–10 mean (B) (source: both maps produced by USGS EROS in Sioux Falls, South Dakota and posted on the USGS Early Warning data website).

Note
Brown areas in the anomaly have below-average NDVI and green areas above-average vegetation densities.

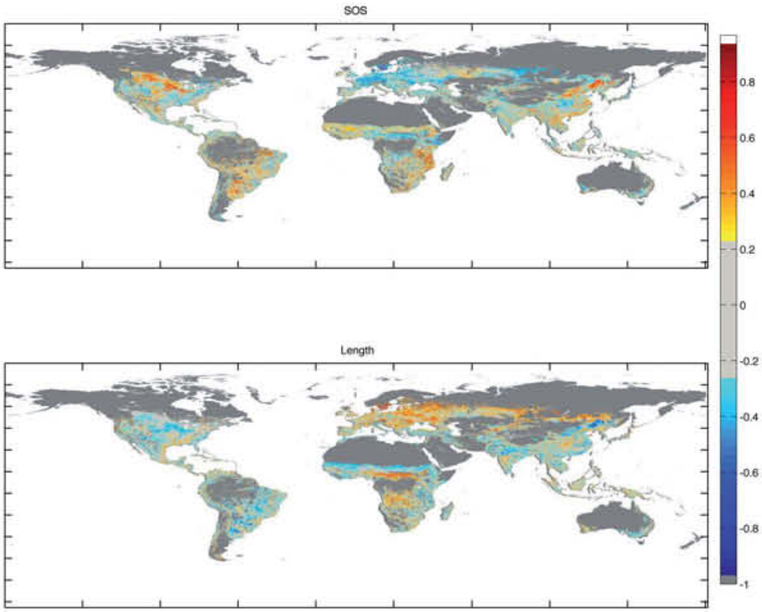


PLATE 9 Temporal trends in phenology metrics derived from models using NDVI data, showing trends in the start of season (top), and length of season (bottom) (source: derived from data presented in Brown *et al.*, 2012).

PLATE 10 Small, weekly cereal market in Mopti, Mali (source: photo by the author).

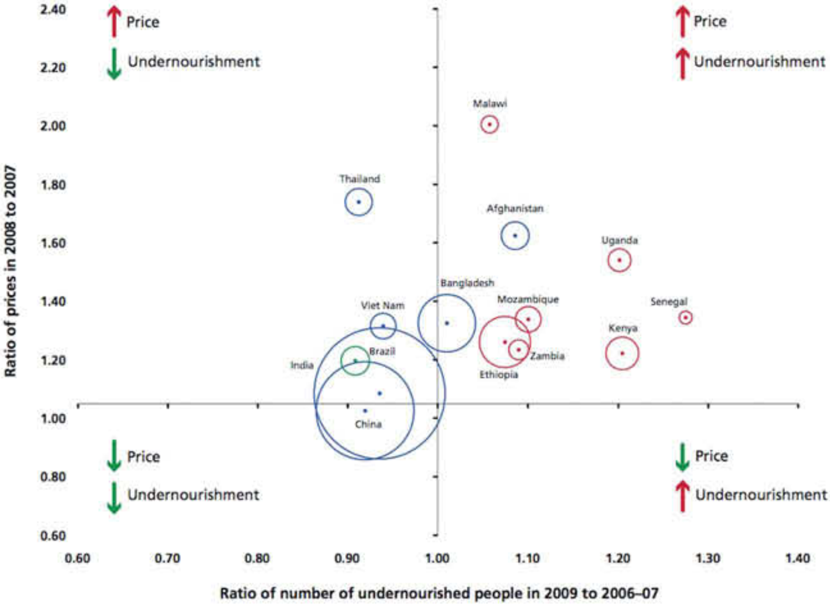


PLATE 11 Differences in resilience to food prices shocks across countries (source: from FAO (2011), copyright United Nations, used with permission).

Note
The size of the bubbles is proportional to the number of undernourished in 2008. African countries are shown in red, Asian countries in blue and Latin American countries in green. Prices used are inflation-adjusted retail prices of major staple foods in main markets, weighted by the population of each market and the share in energy intake of each staple food.

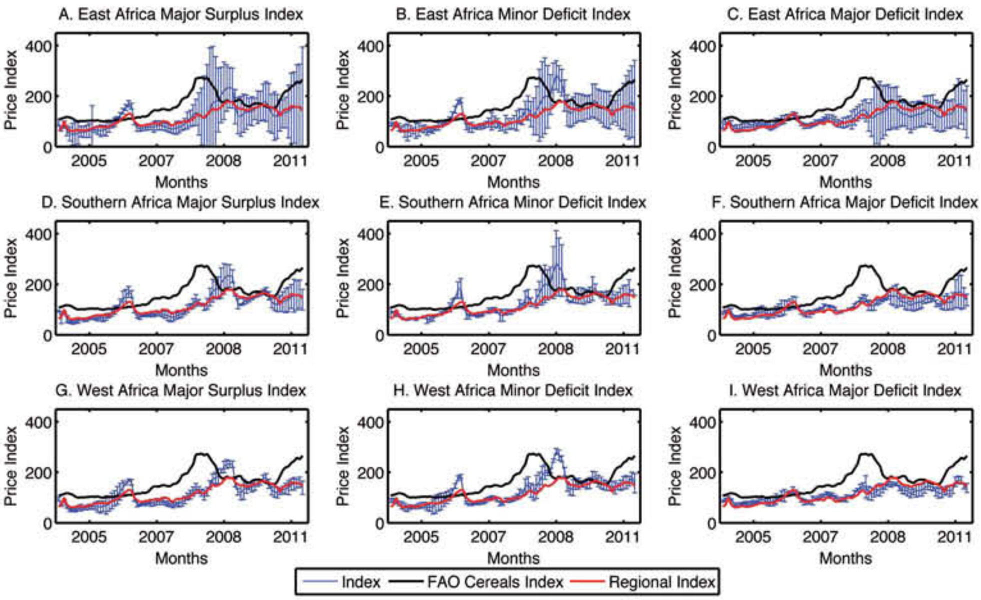


PLATE 12 Regional price indices (source: adapted from Brown *et al.*, 2012).

Note
The plate shows the regional price indices (thick line) from West, East and Southern Africa, plotted with the FAO cereals price (black line) and price indices for major surplus, minor deficit and major deficit regions (thin blue line). Error bars show the spread of prices for each time period among all markets in sample.

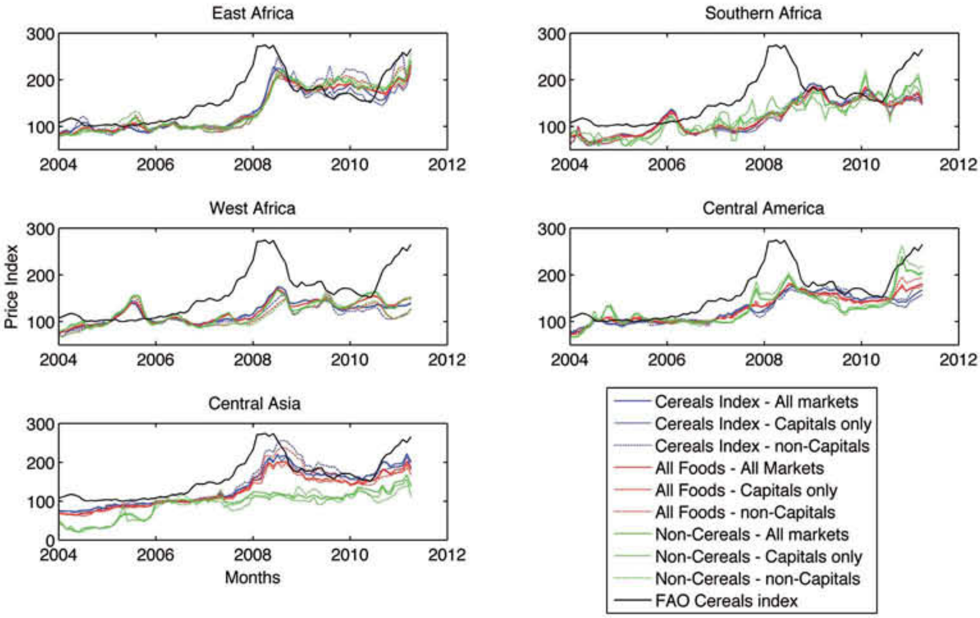


PLATE 13 Regional price indices for West, East and Southern Africa, Central America and South Asia (source: adapted from Brown *et al.*, 2012).

Note

In each figure, the cereals, non-cereals and all commodities, and the capital city markets, non-capital city markets and all markets are given, along with the FAO cereals price index for reference.

PLATE 14 Outdoor vegetable market in Bangkok, Thailand (source: photo taken by the author).

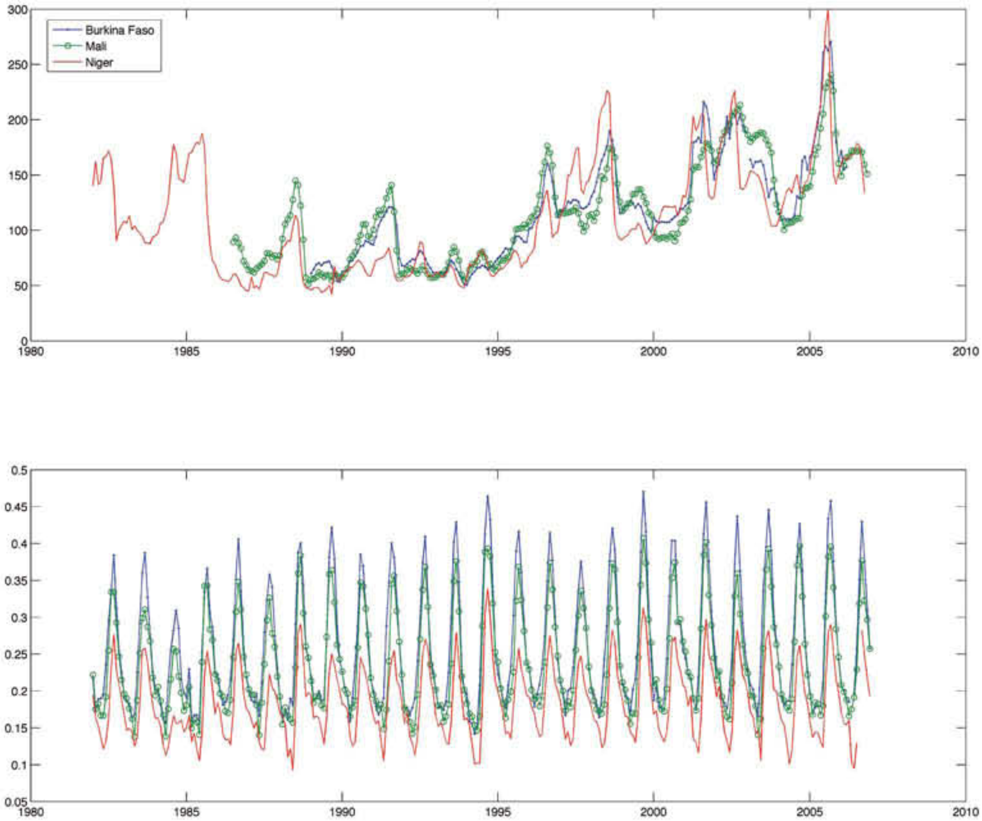


PLATE 15 Averaged millet prices from 1982 to 2007 for Burkina, Mali and Niger (top) and average NDVI for the same periods and regions.

Note
NDVI data are averaged around each market for each time period and averaged across all markets in each country.

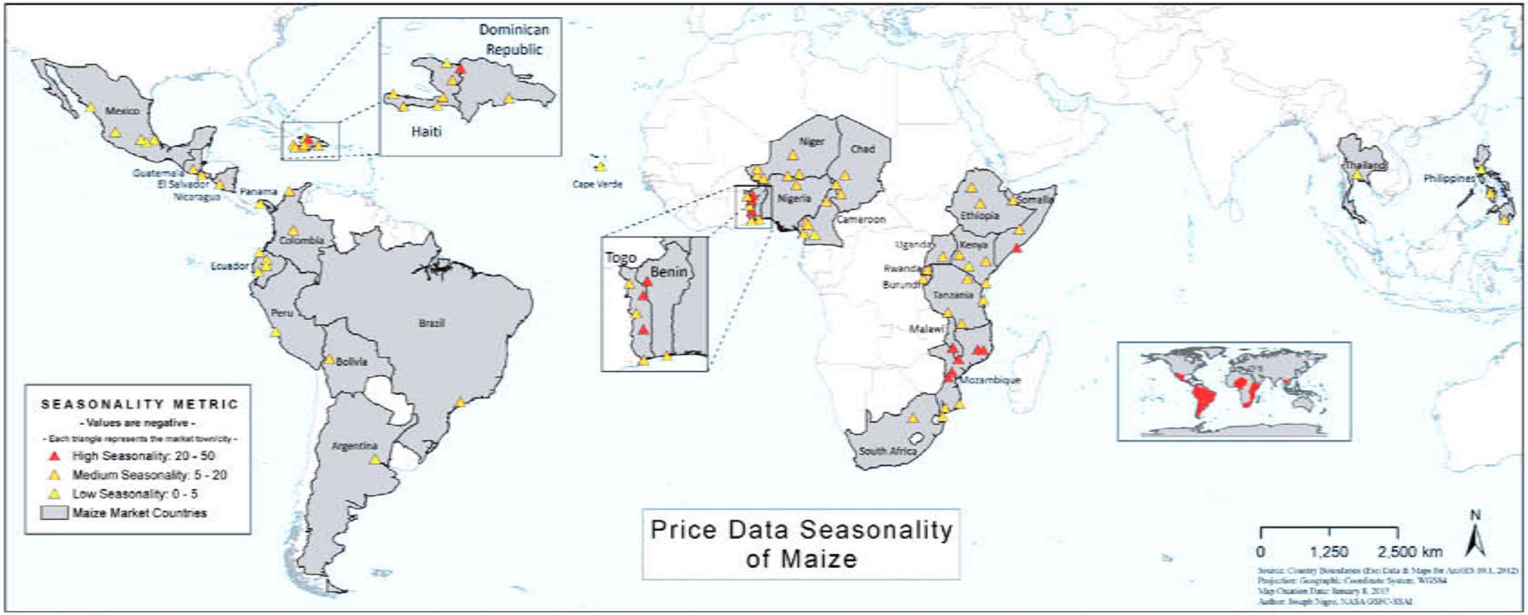


PLATE 16 Map showing the seasonality of maize prices (retail and wholesale) from 2003–11.

Note
Values are the maximum seasonal percent increase over the period of record for maize data.

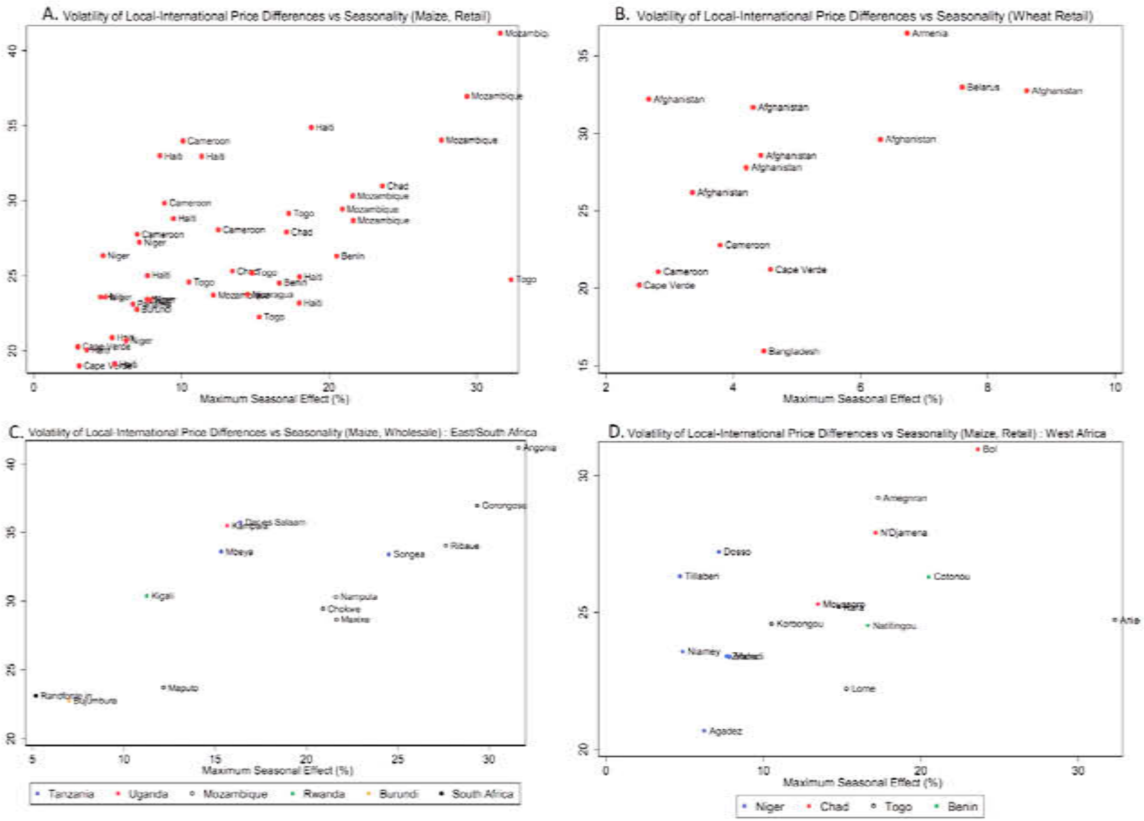


PLATE 17 Scatter plots showing the relationship between maize price volatility and percent difference between local and international commodity prices.

Notes

Scatter plots showing the relationship between maize price volatility (Std. deviation of monthly % change) and percent difference between local and international maize commodity prices (Panel A), volatility of wheat prices vs percent difference between local and global wheat prices (Panel B), East and Southern African maize price vola tility vs seasonality (Panel C) and volatility vs seasonality in maize retail prices in West Africa (Panel D). Each country has multiple cities with maize price time series, thus the multiple instances of the same country name.

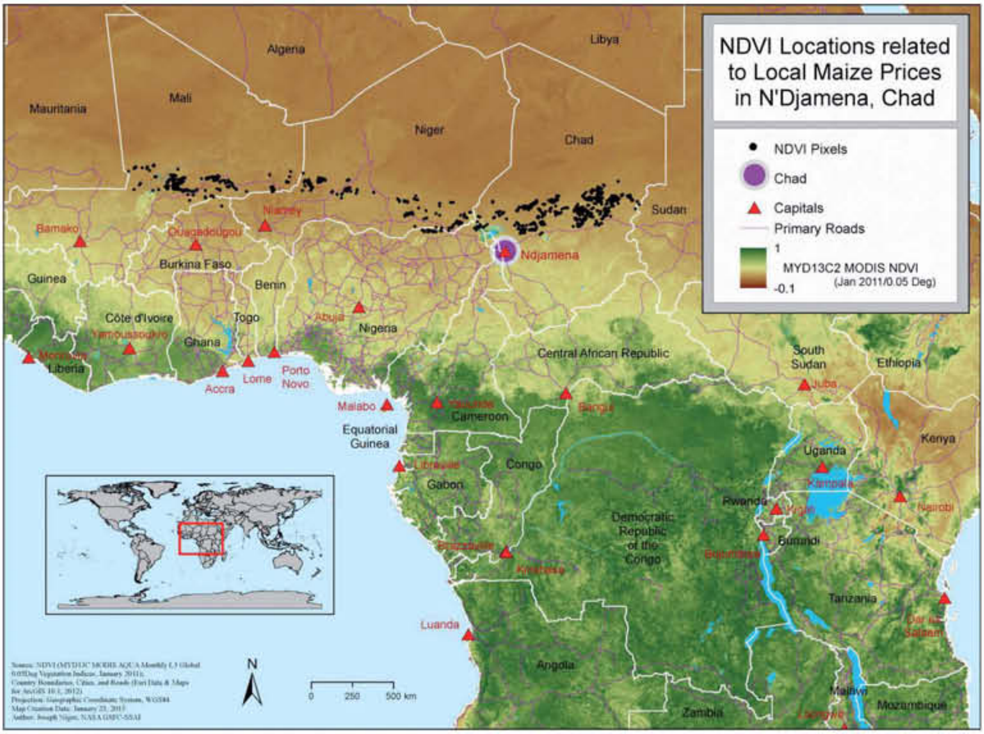


PLATE 18 Map of NDVI pixels related to maize prices in Njamena, Chad during the 2003–08 period.

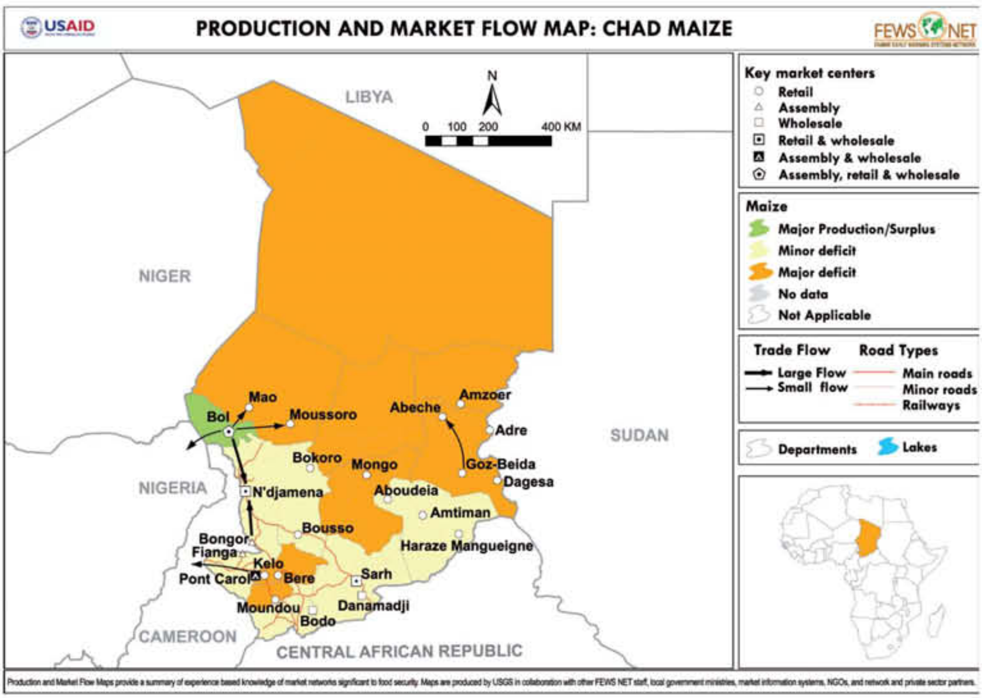


PLATE 19 Trade flow map of Chad from FEWS NET markets and trade division.

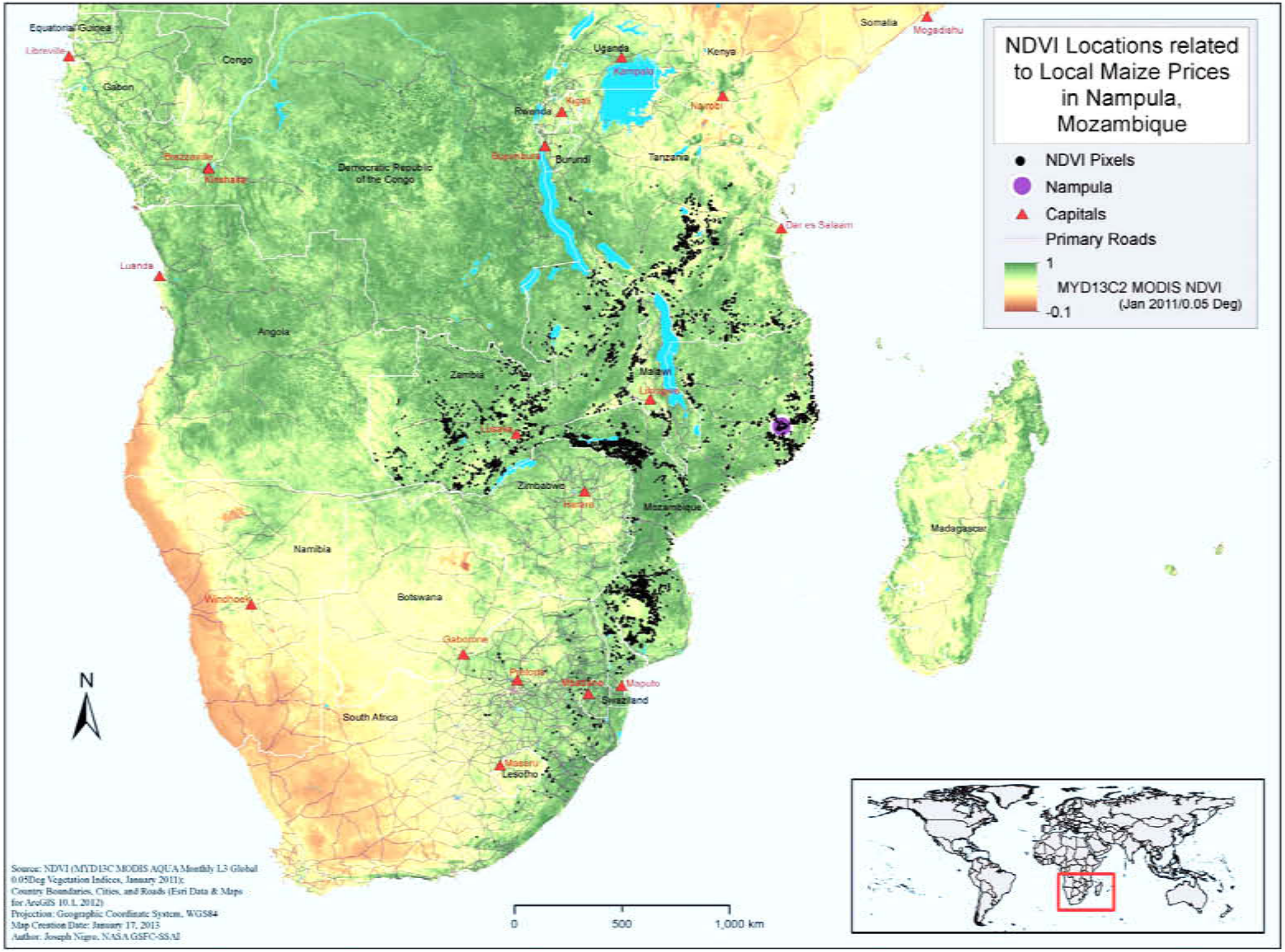


PLATE 20 Map of NDVI pixels related to maize prices in Nampula, Mozambique during the 2003–08 period.

PLATE 21 Trade flow map of Mozambique from FEWS NET markets and trade division.

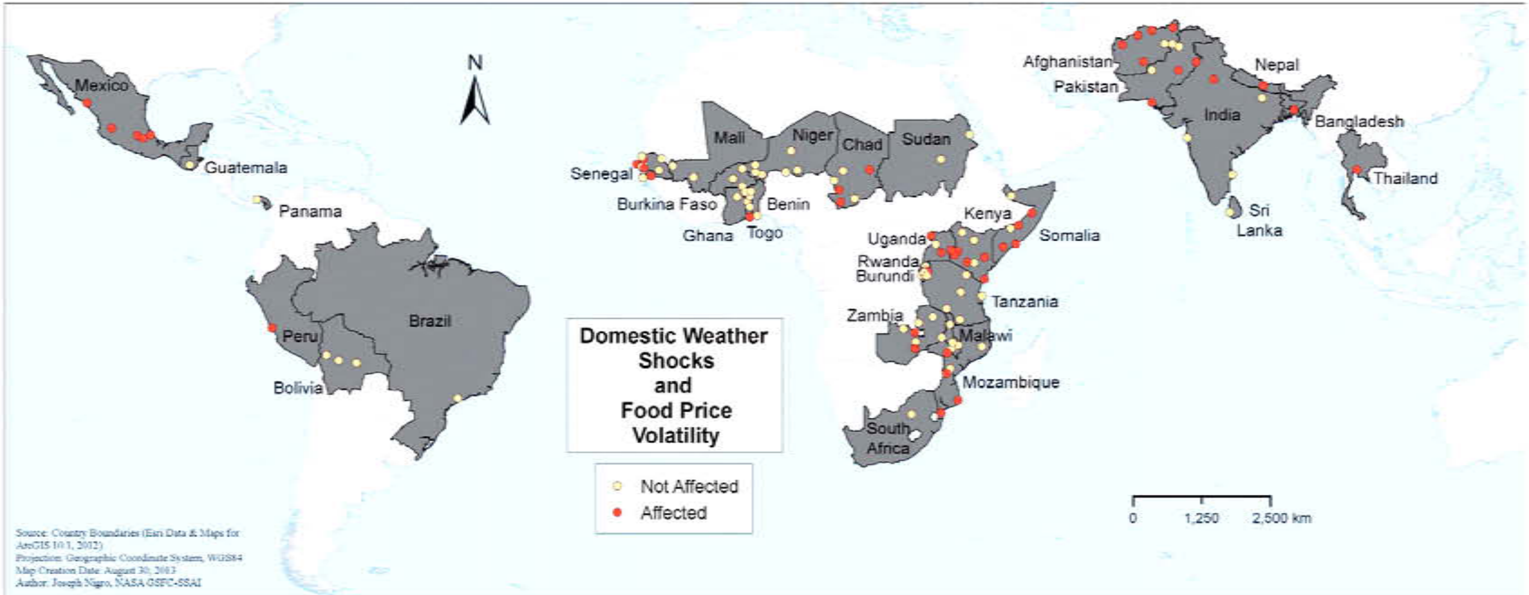


PLATE 22 Map showing impact of weather and international price shocks on local food prices from 2008–12 for rice, wheat, millet, sorghum and maize by location.

PLATE 23 Teff field delineation from fieldwork in Adi Ha, Tigray region, Ethiopia (source: image provided by Bristol Mann, University of Michigan, used with permission).