Sustainability Research Institute
SCHOOL OF EARTH AND ENVIRONMENT

UNIVERSITY OF LEEDS

Food security, Malthus, and the "Perfect Storm": putting current debates about agricultural productivity and climate change into an historic context

Evan D. G. Fraser, Klaus Hubacek, Elisabeth Simelton, Claire Quinn and Andrew Challinor

July, 2009

No. 19

SRI PAPERS

SRI Papers (Online) ISSN 1753-1330

First published in 2009 by the Sustainability Research Institute (SRI)

Sustainability Research Institute (SRI), School of Earth and Environment,
The University of Leeds, Leeds, LS2 9JT, United Kingdom

Tel: +44 (0)113 3436461
Fax: +44 (0)113 3436716

Email: SRI-papers@see.leeds.ac.uk
Web-site: http://www.see.leeds.ac.uk/sri

About the Sustainability Research Institute

The SRI is a dedicated team of over 20 researchers working on different aspects of sustainability. Adapting to environmental change and governance for sustainability are the Institute's overarching themes. SRI research explores these in interdisciplinary ways, drawing on geography, ecology, sociology, politics, planning, economics and management. Our specialist areas are: sustainable development and environmental change; environmental policy, planning and governance; ecological and environmental economics; business, environment and corporate responsibility; sustainable production and consumption.

Disclaimer

Food security, Malthus, and the "Perfect Storm": putting current debates about agricultural productivity and climate change into an historic context

Email: evan@env.leeds.ac.uk

Contents

Abstract

Climate change is likely to impact agricultural productivity and many wonder whether the earth will be able to produce enough food for our growing population in light of changing weather patterns. In both popular and academic writing, this concern is often described as “climate change threatening food security” and arguments often are based on computer models that link climate change scenarios with agricultural productivity models. However, 30 years of work in development studies suggests only a weak link between food insecurity and agricultural productivity. This body of literature argues that food security is a function of economic and political forces rather than environmental constraints. This paper reviews arguments that both link and refute the connection between food security and environmental productivity and concludes that both environmental and socio-economic approaches are necessary to better understand future trends in food security. This integration can be achieved by conducting a series of linked assessments: (1) a modelling based evaluation of changing patterns of agricultural productivity in light of new weather conditions; (2) a statistical assessment to identify the underlying socio-economic variables that led, in the past, to successful adaptation to bad weather; and (3) a local-level (and often participatory) assessment of the specific adaptation strategies used by households.

Key words: Entitlement theory; crop modelling; climate change; Malthus; adaptation, population

Submission date 3-07-2009; Publication date 25-08-2009

About the Authors

Andrew Challinor is a lecturer in Climate and impacts modelling. He trained as a physicist and now works with numerous disciplines on the knowledge base that strengthens the food security and health of populations vulnerable to climate variability and global environmental change.

Evan Fraser is a Senior Lecturer in Sustainable Development. He is an anthropologist by training, and has published historic and contemporary accounts of how socio-economic factors created food security crises.

Klaus Hubacek is a reader in ecological economics who has published on input-output analyses, participatory methods, integrated models and land use change.

Claire Quinn is a Lecturer in Natural Resources Management. She is an ecological social scientist with experience working on interdisciplinary projects both in Africa and the UK. She conducts research on the links between ecological and socio-economic processes in the management and conservation of natural resources.

Elisabeth Simelton is a research fellow working on the socio-economic factors that make agriculture vulnerable to drought. She is a geographer with interest in the impacts of global change on agriculture and rural land use and has worked in rural development projects in Asia. Her current research focuses on adaptive capacity to climate change from global to village scale.

1 Introduction

During the last two years, food security has risen on both the media's and academic agenda. This interest has been driven by the dramatic rise in cereal prices during 2007-8 (Food and Agricultural Organization, 2008), concern about drought in Australia (Catford, 2008), worries about population growth (Lutz et al., 2004), and fears over climate change (Intergovernmental Panel on Climate Change, 2007). For example, in early 2009, John Beddington, the UK government's chief scientific advisor, joined a chorus of high profile scientists who are anticipating a looming crisis of food, energy and water shortages. In Beddington's opinion, the first cause of this crisis is likely to be the "…increased demand for food that is going to be up by about 50% by 2030…". He then went on to point out that "shifts in climate" will cause food production to move northward, benefiting Europe but that to adapt the "more traditional farming nations" will need "…to develop more advanced pesticides or more hardy crops to boost yields…" (Beddington, 2009 on-line edition). While Beddington's comments were intended as a wake up call to politicians and the general public, his conclusions echo that of a large and highly reputable scientific body of literature. Recent articles in some of the world's most prestigious scientific journals argue (among other things) that current projections of global food production under climate change scenarios have over-estimated the beneficial effect of carbon dioxide fertilization (Long et al., 2005), that the higher temperatures projected by climate change models will decrease agricultural productivity (Battisti and Naylor, 2009), and that these factors mean climate change will reduce global food security (Lobell et al., 2008). More specifically, rises in global mean annual temperature of up to two degrees, centigrade, are expected to reduce yields in low latitude regions, while benefiting crop production in many higher latitude areas. Increases of more than two degrees are expected to reduce yields across the globe (Easterling et al., 2007). One proposed solution is to use agricultural management practices that increase the amount of carbon stored by the soil (through, for example, low tillage agronomy) because increasing the amount of carbon in soils will not only help mitigate climate change but also increase agricultural productivity thereby enhancing food security (Lal, 2004). Scholars also expect that demand for cereal will rise by 56% and for livestock by 90% between 1997 and 2050 and that it will be challenging to meet this demand using current agricultural technology (Rosegrant et al., 2002). As a result, some authors argue that biotechnology offers one way that a pending food shortage can be averted. Despite controversy over biotech, China has invested heavily in trying to engineer more productive crop varieties (Huang et al., 2002).

It is important to highlight that an assumption runs through the literature just cited – namely, that a food security crisis is pending because our capacity to produce food is unlikely to meet our needs. Even those authors who argue that food security is determined by more than agricultural productivity seem to end up focusing on this issue. For example, Brown and Funk (2008) begin their article on in the journal *Science* with a broad conceptualization of food security but then bring their argument back to the link between productivity, population and hunger and conclude that polices to address food security should focus on "…investing in agricultural inputs such as fertilizer and improved varieties that can dramatically increase yields…" (p. 581). Schmidhuber and Tubiello (2007)'s article in the *Proceedings of the National Academy of Sciences* provides a full account of how climate change may affect food availability, stability, utilization, and access (four commonly attributed aspects of food security see (Ericksen, 2008)). However, they point out that of all the components of food security, only food availability (i.e. supply) is routinely quantified in the literature.

In contrast to this literature, many social scientists posit that social, economic, political and institutional factors are more important in determining how food is produced, distributed and consumed than agricultural productivity (Sen, 1981). According to this body of literature, understanding food security requires understanding both the ways people obtain food as well as the ability of the environment to produce it (Watts and Bohle, 1993). For example, there is only a weak link between environmental conditions that affect agricultural productivity and indicators of food insecurity. Furthermore, comparative work on "environmentally induced famines" (defined as cases where an environmental trigger seemed to caused hunger related deaths) reveals that socio-economic and institutional factors created the conditions whereby the environmental problem affected food security (Fraser, 2007, Fraser, 2006). Such cases include the Ethiopian famine in the 1980s, which was ostensibly caused by a drought (Corbett, 1988, Comenetz and Caviedes, 2002), famines in India in the 1870s, which seem to have been triggered by El Niño events (Davis, 2001), and the Irish Potato Famine, which occurred where rainy years created ideal conditions for a fungal pathogen to spread (Fraser, 2003). In each of these cases, it is clear that the environmental trigger was simply the final shock to hit a food system that was already under a great deal of socio-economic and political stress.

In many ways, the research reviewed so far in this paper is only a relatively recent part of a 200 year old debate started by Thomas Malthus who hypothesized that population growth would inevitably result in the demand for food over-shooting agricultural productivity (Malthus, 1976 edition). Over time, many have argued about this position (Watts, 2000, Spengler, 1971). However, given the recent interest in food security that has been sparked to a large extent by research on the link between climate change and agricultural productivity (Challinor et al., 2009a), the purpose of this paper is to revisit the origins and development of the debates on food security. In particular, this paper will explore the key elements of this 200 year debate on whether food security is necessarily linked with the supply of food and agricultural productivity as Malthus thought, or whether it is better assessed through an understanding of how different groups of people obtain food by using a socio-economic perspective. This paper will finish by reviewing recent scholarship that tries to bring these two perspectives together.

2 Malthusianism or supply oriented approaches to assessing food security

Over two hundred years ago, the Reverend Thomas Malthus made a seminal contribution to explaining population growth and hunger in his *Essay on Population*. Observing the fast-growing Irish population, he hypothesized that a limited amount of agricultural land and high population growth would inevitably lead to hunger, famine, disease and death because: "...population, when unchecked, increases in a geometrical ratio...[while] subsistence increases only in an arithmetical ratio..." (Malthus, 1976 edition, Chapter 1). Coming at a time when famines ravaged much of the colonial world (in addition to the Great Irish Potato Famine that claimed 1 million lives and forced another 1 million into exile, between 1876 and 1902 approximately 30 to 60 million people died of hunger in India, China and Brazil (Davis, 2001)) the

“Malthusian argument” provided a justification for political inaction. Lord Lytton, Viceroy of India during a catastrophic late 19th century famine, remarked that the calamity in India was caused by the Indian population’s “…tendency to increase more rapidly than the food it raises from the soil…” (Quoted in: Davis, 2001 p. 32). Malthus’ theory provided a ‘natural law’ for inequality and the misery of the masses, and was immediately very influential. For example, Charles Darwin (1809-1882) was directly influenced by Malthus and wrote in his autobiography (published in 1876):

> In October 1838, that is, fifteen months after I had begun my systematic inquiry, I happened to read for amusement Malthus on Population, and being well prepared to appreciate the struggle for existence which everywhere goes on from long-continued observation of the habits of animals and plants, it at once struck me that under these circumstances favourable variations would tend to be preserved, and unfavourable ones to be destroyed. The results of this would be the formation of a new species. Here, then I had at last got a theory by which to work.

Malthus’ ideas were enthusiastically received by Victorian policy makers and this reflected what a modern commentator described as: “…the overall societal situation and mind of the industrializing Victorian England” (Seidl and Tisdell, 1999 p. 397). Policy makers who accepted the Malthusian argument, viewed famine as an entirely natural – though regrettable – way to bring humanity back into balance with the environment. This political opinion was driven by ‘invisible hand of the market’ (Smith, 1998) mixed with the Social Darwinian assumption that the British Empire ruled the world due to the superiority of its value system (see Woodham-Smith (1962) for an investigation of the Irish Famine in light of British Politics). Any policy intervention designed to halt a famine risked being attacked in London as making the problem worse and one British cabinet minister from the 1870s remarked that: “…every benevolent attempt made to mitigate the effects of famine…serve but to enhance the evils resulting from overpopulation” (Sir Evelyn Baring (then finance minister), quoted in Davis, 2001 p. 32).

Modern assessments tell a very different tale. While each of these Victorian famines was precipitated by an environmental trigger, the effects of the famine were exacerbated by a host of socio-economic factors that both made agricultural productivity sensitive to climatic problems but also prevented starving people from accessing the food that was available. Population growth seems to have little to do with famine, and in Ireland it was poor and isolated communities that suffered, not those with high population growth rates (Fraser, 2003). While it is an exaggeration to suggest that the Colonial powers did nothing to ease the pain (O'Grada, 1989), relief efforts were hampered by those who had their worldview confirmed by Thomas Malthus’ logic.

The influence of Malthus’ ideas have waxed and waned over the decades. In the early 20th century, the original flavor of the Malthusian apocalypse reemerged with John Maynard Keynes who said “…the ‘Malthusian devil,’ chained for more than half a century, was unleashed again” (quoted in Ely and Wehrwein, 1948 p. 10). Keynes was referring to the period during and after World War I when supplies of food and fibre could not keep up with demand. In the mid-20th century, Garrett Hardin (author of *The Tragedy of the Commons*) used Malthusian logic when he suggested that any attempt to help the poor will result in a situation in which the "…less provident and able will multiply thus bringing eventual ruin upon all who share in the commons" (Hardin, 1974 on-line edition). Malthusian logic was also applied to early computer models that attempted to anticipate the future of the planet in light of rising population. The best known example of these models is *The Limits to Growth* (Meadows and Club of Rome, 1972).

Malthus, who has been described as "… a 'philosopher' who first saw the importance of the limiting factor of environment on human material process" (quoted in Seidl and Tisdell, 1999 p. 397), also had enormous influence on the development of one of the cornerstone concepts in modern ecology: carrying capacity. Ecologists sometimes define carrying capacity based on Justus Freiherr von Liebig's *law of the minimum* that suggests the size to which a population can grow will be limited by whatever essential nutrient is least abundant in an ecosystem (Liebig, 1859). This has subsequently been refined and, today, carrying capacity is usually defined as the theoretical maximum population that an area can sustain under given technological capacities and natural constraints (Daily and Ehrlich, 1992). The idea of there being a carrying capacity for human populations has been extremely influential and is evoked in Stocking's seminal paper in *Science* when he argues "the dynamism of the links between soil resources and society provides a platform for examining food security…[because] in most agro-ecosystems, declining crop yield is exponentially related to loss of soil quality" (Stocking, 2003 p. 1356). It has also been claimed that water, more than any other factor, determines the capacity of a region to support human populations (Cohen, 1995).

The theory that the environment has a carrying capacity has also been extremely influential in shaping broader debates over sustainable development and forms the basis for projections of how many people the earth can sustainably support. A recent and popular version of this is the *ecological footprint* that tries to relate the full impact of consumer behaviour to the amount of land taken up by these actions. This concept was established by Wakernagel and Rees (1995) who reasoned that almost everything we do can be related to land use: land used for crops, land used for transportation, land used for garbage disposal, and even land that should be used to plant trees to sequester carbon emitted by burning fossil fuels. NGOs have used "ecological footprinting" exercises to try to calculate "how many earths" the modern world currently uses to illustrate that we have overshot the global carrying capacity (e.g. the Global Footprint Network suggested that on September 23, 2008, the earth "used up" the natural resources that were produced in that year. They referred to this as "global overshoot day" (Global Footprint Network, 2008)).

3 Non-Malthusian or demand oriented approaches

There are problems, however, with this logic. The Malthusian-inspired notion of there being a carrying capacity assumes relatively constant environmental conditions and (for humanity) stable technology. Both these conditions are questionable. In terms of the environment, modern ecological theory suggests that environmental conditions are rarely constant and the field of "multiple equilibrium" ecosystem dynamics argues that it is impossible to calculate the theoretical maximum populations a region can sustain (Vetter, 2005, Dougill et al., 1999). When this logic is applied to humanity, changing socio-economic conditions make estimating the earth's "human carrying capacity” unrealistic:

> How many people Earth can support depends in part on how many will wear cotton and how many polyester; on how many will eat meat and how many bean sprouts; on how many will want parks and how many will want parking lots. These choices will change in time and so will the number of people Earth can support (Cohen, 1999 p. 62).

In terms of technology**,** Malthusian analyses traditionally ignore or downplay the role that innovation, technology and ingenuity play in increasing food production. This made sense at the time. Malthus lived at the end of the relatively static pre-industrial world, which was characterized by a relatively steady-state economy that had relatively modest technology. As such, he was convinced that the demand for food would inevitably outstrip the supply of food. In the last 200 years, the reverse has been true. In almost every region around the world, food production has grown faster – sometimes much faster – than population growth. In many cases, extra population has even directly stimulated new agricultural technologies such as terracing hillside that is impossible without high population densities (Boserup, 1981). As a result of agricultural innovation, humanity has benefited from healthier and longer-lived human populations in most regions (Simon, 1981).

Hence, most social scientists interested in food security today have shifted their attention away from analyzing patterns of food production to exploring the socio-economic context in which food is obtained by consumers. Demand-oriented methods themselves fall into two general categories. The first is expert led and food security policies that come out of this approach are directed by data that attempt to categorize people as nutritionally poor if they fail to achieve externally decided health standards (say by seeing if children are below a certain weight by a given age). This is in contrast with more participatory approaches that ask the people themselves to describe their own welfare (Nb. sometimes participatory approaches are sometimes referred to welfarist or hedonic, while expert led approaches are referred to as non-welfarist or non-hedonic.)

While both approaches are difficult to apply in the field, many of the expert led methods are fraught with methodological problems. Almost every way of assessing nutritional deficiencies is undermined by some practical consideration that makes this whole approach problematic (Foster, 1992). Furthermore, based on this approach alone, policy-makers are equipped with nothing more than raw data that is of questionable usefulness. For example, nutritional problems, health deficiencies, and stunted development are all symptoms of hunger and malnutrition. Merely identifying the symptoms will provide no guidance on how to solve this problem. As a result, policies that emerge from such methods may fail to take into account the causes of hunger.

In contrast with these “expert” approaches are more participatory methods that make comparisons of welfare based on the expressed preferences of individuals. This approach is based on the idea that people will have a “preferential ordering of goods” that represents a “utility function” (Ravallion, 1994 p. 4). In other words, people are able to recognize what is useful to them, and will choose those things. In this way, you could present a community with a number of different food security policies and let them decide the most appropriate one for their situation. It is simply a matter of asking people what they want and whether they have the means to obtain it. These participatory approaches match a broader trend in the social sciences away from a focus on large-scale explanatory theory to research that explores local factors. For example, in 1995, one of the pioneers in this shift argued that "…the defence of the local is a prerequisite to engaging with the global…" meaning that local assessments are required to understand how global problems manifest themselves in specific localities (Escobar, 1995, p. 226). This position is backed up by empirical studies that show how externally imposed objective indicators designed to quantify broad concepts like food security or sustainability may actually reflect more about the researcher doing the study than the problem itself (Morse and Fraser, 2005).

But there are also a number of problems associated with these participatory approaches. First of all, collecting participatory data is very time consuming, costly and difficult to organize and facilitate (Fraser et al., 2006, Stringer et al., 2006). Second, people may not always be the best judge of their welfare and the pursuit of individual welfare may not enhance the welfare of the larger community. For example, where there is open access to a scarce resource (such as land) or in cases where resource tenure is changing (Ostrom, 2001), it is often in the best interests of the individual family to have many children so that they can capture a larger share of the economy (Hardin, 1968). If, however, all families follow this strategy, there may ultimately be fewer resources and may thus decrease everyone's well-being.

There is a third way for assessing food security that avoids some of the problems just outlined. This approach focuses on the ability that an individual or single family has to deal with their own problems. The most famous proponent of this approach is the Nobel laureate, economist Amartya Sen, who argues that the study of food security should focus on people's capability to obtain food. Sen defines capability as the ability to undertake specific objectives that are useful to the family (Sen, 1981, Sen, 1987). The benefit of looking at food security from the perspective of capabilities is that policy makers need not pre-suppose how people should be living or the types of food people should be eating. Rather, this approach measures how much freedom an individual or family has. The disadvantage of this approach is that those who use it tend to focus on measuring economic indicators like household income as a proxy for the family's capability to obtain food. However, some people, especially women, do not work for a wage and when faced with hunger some people will not only use cash to find food. People may switch to inferior foods, cease waged labour and return to subsistence production. As a result, a simple poverty-line approach may not pick up very important aspects of food security (Ravallion, 1996). One study on single-parent households in Africa illustrated this by observed that if the income of female-headed households goes up, then the household's food, health, and education budgets grew by 3-6 times more than if the same income was given to male headed households (Haddad et al., 1997). Keopman (1997) backs this general conclusion up by illustrating that in most situations in rural Africa, household incomes are not generally pooled. Rather, women tend to be responsible for food, while men are generally responsible for housing (Haddad, et. al., 1997, p. 130). Traditional methods of poverty assessment, which rely on the household as the basic economic unit in a society. may not adequately explain the complexities of gender relations.

To address these issues, Sen also coined the term *food entitlement* to describe the many different ways in which a group obtains food: the failure to obtain food, therefore, becomes an "entitlement failure" and can occur anywhere between the producers and the consumer of food. To fully understand food entitlements, it is necessary to measure economic assets (such as money in a bank account) but also human, social, and natural capital too:

> In each social structure, a person can establish command over some alternative commodity bundles (any one bundle of which he or she can choose to consume)...The set of alternative bundles of commodities over which a person can establish command will be referred to as this person's entitlement (Dreze and Sen, 1989 p. 5).

For example, the way a person obtains food (or achieves their "entitlement") can come from either direct sources (e.g. a farming family that grows its own food), indirect sources (e.g. a labouring family that exchanges money for food and obtains a regular income) or transfers (e.g. charity and food aid). Acute malnutrition and famine occur when a person's or a community's "entitlement" is disrupted. This can be an indirect or demand-side failure, which occurs when people lose their purchasing power through unemployment, falling wages, rising food prices, or inflation and do not have the assets to either grow their own food or rely on others for charity (Sen, 1988).

Entitlement theory has been further developed into "the sustainable livelihoods approach" that looks at how households deploy different types of "capital asset" to maintain food security (Scoones, 1998). The different types of capital asset that are assessed through a sustainable livelihoods approach include social capital (i.e. networks of friends and relations that can provide assistance in times of need) human capital (a person's health and education) financial capital (income or savings), physical capital (the built infrastructure) and environmental capital (ecological feature such as soil quality or access to forests) (Bebbington, 1999). In addition, the sustainable livelihood approach also examines broader contextual questions and this involves assessing both the household's exposure to climatic shocks such as floods or droughts, as well as broad trends including gradual environmental or population change. Finally, the livelihoods approach also suggests that researchers must assess institutional processes, thus providing insight into how laws and policies are made. By providing a consistent framework that focuses a researcher's attention on assets, context and processes, the livelihoods approach has been used to evaluate case studies that describe how households maintained food security during environmental shocks (Hitchcock, 2002). One challenge inherent in this approach, however, is that while each of these individual livelihoods studies provides a wealth of rich information, each tends to be so contextually specific that discerning general trends is very difficult. So, while there have been attempts to distil from this literature generic lessons and frameworks (Ericksen, 2008) these frameworks tend to be conceptual and it is recognized that they are still too descriptive and that more analytic frameworks are required (Turner et al., 2003).

4 Combining Approaches

The literature reviewed in this paper suggests that there is a broad spectrum of approaches to food security that, we think, can be categorized along two dimensions.

The first dimension relates to the causes of food security being studied in a particular piece of research. This dimension ranges from those researchers who assume food security has a *material* cause (namely a lack of food) to those who approach food security as resulting from the *structure* of relationships within society that affects people's ability to demand food. The Malthusian approaches described in the introduction and section 2 of this paper would be examples of quite materialistic explanations of food security while the livelihoods and entitlement approaches described in section 3 would be examples of a more structural approach.

The second dimension ranges from those specific pieces of research that result in contextually rich *descriptive* explanations to those that are more *prescriptive*. Descriptive studies include those resulting from the sustainable livelihoods tradition while prescriptive studies include those that assess food security through coupled crop-climate models (see section 2). Philosophers of science often use the term *nomothetic* to refer to the prescriptive types of research and *ideographic* to describe research that seeks to explain how or why a specific event occurred (York and Clark, 2007).

We propose that a complete analysis of food security should include elements that run across both these dimensions (prescriptive/descriptive and material/structural) but that it is not possible for a single piece of research to accomplish all these factors. Rather, we propose an integrated and iterative research framework (figure 1).

Prescriptive (or nomothetic) and material assessments of food security (represented by the top-left hand corner in figure 1) would employ both crop and climate modellers to identify the regions in the world where yields are projected to decline due to changing environmental conditions. Rather than coming up with single projections, however, these modellers can use combinations, or ensembles, of crop simulations (Challinor and Wheeler, 2008a, Challinor and Wheeler, 2008b) combined with ensembles of climate simulations (e.g. Murphy et al., 2004) to create a range of projections that capture the biophysical uncertainty of their models (Challinor et al., 2009b). This approach lends itself to creating “business as usual” scenarios, where current agricultural management (including cultivar choice) is assumed to be constant (or is following a long-term trajectory), as well as simulating the effect of “potential” adaptations and shocks. For example, by using the genotypic properties present in existing cultivars of food crops, it is possible to project the potential effect of adaptation by assuming that farmers will switch to those cultivars bred to tolerate new environmental conditions (Challinor, Available on line). Through this, researchers can both identify regions where there is the potential to adapt to climate change as well as predicting short-term harvest fluctuations (E.g. Challinor et al., 2005).

Since this modelling approach does not provide any insight into those areas where adaptation is likely, we propose that crop-climate models must be “grounded” in local-level field studies. This would draw on the more structural and descriptive methods illustrated in the bottom left hand corner of figure one. To do this, researchers must assess entitlements through a sustainable livelihoods approach that uses local surveys and/or participatory methods to identify the specific ways different types of communities and households maintain food security.

To bridge these two types of research, we propose that a statistical approach is useful to identify the socio-economic factors that are commonly associated with successful adaptation (illustrated in the centre of figure one). For example, one already published "descriptive and structural" study on agricultural vulnerability highlights the importance of rural labour that provides the means by which farmers adapt to problems (Fraser and Stringer, 2009). This hypothesis has been tested statistically using four decades of provincial scale harvest and meteorological data from China and results suggest that rice harvests are indeed better buffered against drought in regions with abundant rural labour but that extra labour does not affect the extent to which wheat harvests decline during droughts (Fraser et al., 2008). Using a statistical approach makes it is possible to both identify and weigh the key socio-economic factors that drive different aspects of food security in different contexts (Simelton et al., Available on line). While still at a preliminary stage, this statistical approach provides a basis for using the socio-economic insight that come from descriptive research to help interpret crop-climate models.

Taken together, we conclude that an iterative research process is required that allows insights gleaned from one approach to inform the others (illustrated through the arrows on figure 1). For example, it is possible to imagine the types of "bottom up" steps that start from descriptive/structural research in specific regions but that results are then "up-scaled" to help inform the creation of prescriptive/material predictive tools (this is graphically illustrated by the right-hand "bottom up" arrows on figure one). This might include:

1. Descriptive / Structural Research to explain how and why communities adapted to (or suffered from) past environmental problems. This leads researcher to establish key hypotheses about the socio-economic factors that enhance/obstruct adaptive capacity in different types of areas.
2. These hypotheses are tested statistically to identify and weigh the importance of key socio-economic indicators that are associated with food security in different contexts (e.g. abundant rural labour is important for maintaining harvests during droughts in China's rice producing regions but not for wheat production).
3. These socio-economic indicators can be used to interpret crop-climate models to inform analyses that try to anticipate where climate change may affect yields.

Equally, it is possible to imagine the types of "top-down" steps that would use the results of crop-climate models and work towards the local scale research (this is illustrated by the left-hand arrows in figure 1). This might include:

1. Crop-climate models that are used to identify regions where crop yields are likely to decline due to changes in biophysical constraints.
2. This could result in an analysis of the socio-economic characteristics of these vulnerable regions to determine if the capacity to adapt resides in these areas through a statistical analysis of the factors associated with past adaptation and current or potential future behaviour.
3. These projections could be used to stimulate discussions with local stakeholders in vulnerable areas to pro-actively identify adaptation pathways and establish policy that can enable these adaptations.

To close, we are not advocating or prioritizing one direction over the other or suggesting that any of these three broad approaches is "better". Rather, our goal is to suggest that it is the process of moving between these types of analyses that is important. By developing a research framework that incorporates all three approaches/scales, we hope that a more sophisticated and nuanced understanding of how climate change may affect food security in the future would emerge.

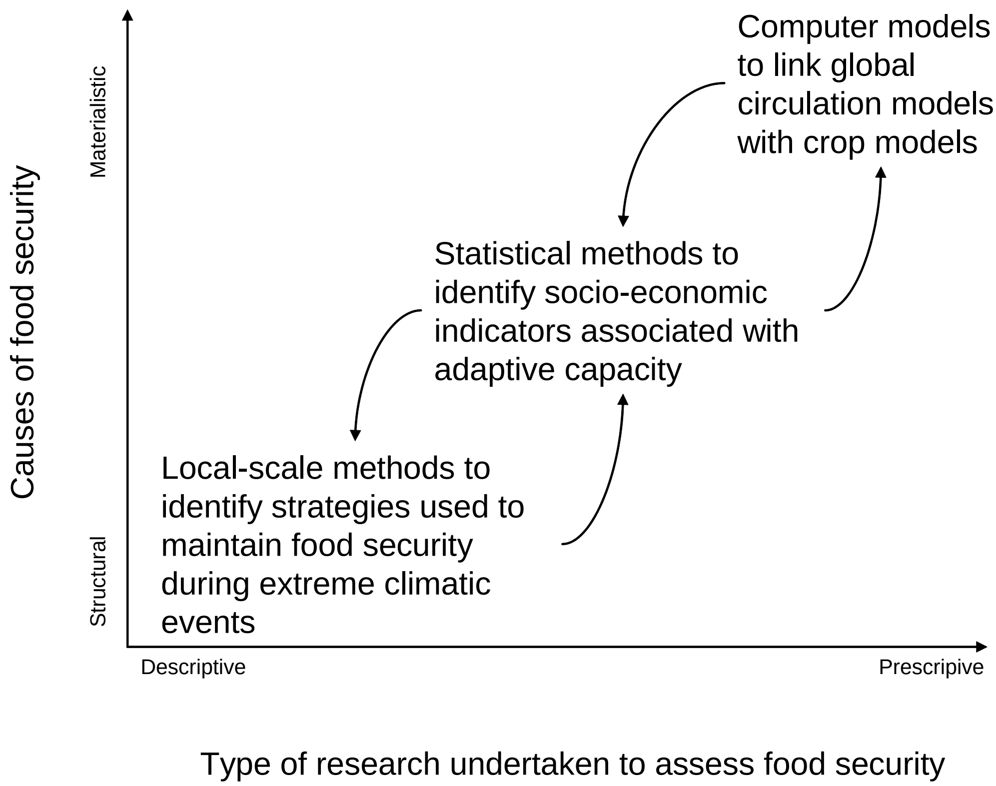

Figure 1: Heuristic food security research framework that incorporates two types of research (*descriptive* research that is usually qualitative and explores the details of unique situations and *prescriptive* research that is typically quantitative and explores general trends) and two common conclusions about what causes food security (*materialistic* explanations of food security that assume food security is a material phenomena related to the presence of food and *structural* explanations that show food security results from societal structures). Within this matrix, three methodological approaches for assessing food security are illustrated. These three approaches need to be integrated to create a holistic understanding of food security under climate change. This integration is reflected in the arrows, showing how models need to be informed from the "bottom up" (right hand arrows) and model outputs need to be used to help enhance adaptation from the "top down" (left hand arrows).

5 Conclusions

Malthusians, neo-Malthusians and others who inherited his ideas, offer a prescriptive and materialistic explanation for the causes of food insecurity that is both simple and enduring because it focuses on the ability of the earth to produce calories. Therefore, it is unsurprising that this approach has provided an ontological foundation for many of our projections of food security under climate change. Hunger and malnourishment, however, are not well correlated with agricultural productivity but result from intervening socio-economic factors. As a result, most social scientists have shifted their focus to the socio-economic context in which food is produced and whether people have the ability to obtain food. This body of literature has provided us detailed insights to the causes of specific problems (such as the cause of specific famines) but has not contributed in a meaningful way as yet to formal modeling work on likely impacts of climate change on food security. In our opinion, assessments of how climate change will affect food security in the future need to combine these approaches by bringing together the formal computer models that capture our understanding of how climate change may affect productivity with two other factors: (1) statistical analyses that can be used to identify those socio-economic factors that are often associated with adaptation; and (2) Local-scale research that can help identify specific adaptation strategies and capture the complexity of how different households obtain food. None of these approaches is “better” than another, and none should be prioritized. The key is for researchers working on one aspect of food security to actively seek collaborators working in other modes. Research teams need to be formed to foster communication and integration across these scales, thereby allowing for a more sophisticated understanding of how climate change may affect food security in the future.

Acknowledgements

Thanks to Dr. Emma Tompkins (University of Leeds and the UK’s Department for International Development and Dr. Lindsay Stringer (University of Leeds) for commenting on early drafts of this paper. This work was funded by (1) the UK’s Economics and Social Research Council through an interdisciplinary research fellowship, (2) the ESRC’s Centre for Climate Change Economics and Policy, and (3) the Natural Environment Research Council’s Quantifying and Understanding the Earth System’s Global Scale Impacts Project.

References

Battisti, D. S. & Naylor, R. L. (2009) Historical Warnings of Future Food Insecurity with Unprecedented Seasonal Heat. *Science,* 323**,** 240-244.

Bebbington, A. (1999) Capitals and capabilities: a framework for analyzing peasant viability, rural livelihoods and poverty. *World Development,* 27**,** 2021-2044.

Beddington, J. (2009) Global crisis to strike by 2030. *Interview with BBC,* Available on line at: http://news.bbc.co.uk/1/hi/uk/7951838.stm.

Boserup, E. (1981) *Population and technological change: a study of long-term trends,* Chicago, University of Chicago Press.

Brown, M. E. & Funk, C. C. (2008) CLIMATE: Food Security Under Climate Change. *Science,* 319**,** 580-581.

Catford, J. (2008) Food security, climate change and heath promotion: opening up the streams not just helping out down stream.

Challinor, A. (Available on line) Towards the development of adaptation options using climate and crop yield forecasting at seasonal to multi-decadal timescales. *Environmental Science & Policy,* In Press, Corrected Proof.

Challinor, A., Ewert, F., Arnold, S., Simelton, E. & Fraser, E. (2009a) Crops and climate change: progress, trends, and challenges in simulating impacts and informing adaptation. *Journal of Experimental Botany,* Available on line.

Challinor, A., Osborne, T., Morse, A., Shaffrey, L., Wheeler, T. & Weller, H. (2009b) Methods and resources for climate impacts research: achieving synergy. *Bulletin of the American Meteorological Society,* In press.

Challinor, A. J., Slingo, J., Wheeler, T. & Doblas-Reyes, F. (2005) Probabilistic hindcasts of crop yield over western India. *Tellus,* 57A**,** 498-512.

Challinor, A. J. & Wheeler, T. (2008a) Crop yield reduction in the tropics under climate change: processes and uncertainties. *Agricultural and Forest Meteorology,* 148**,** 343-356.

Challinor, A. J. & Wheeler, T. (2008b) Use of a crop model ensemble to quantify CO2 stimulation of water-stressed and well-watered crops. *Agricultural and Forest Meteorology,* 148**,** 1062-1077.

Cohen, J. (1999) Population Growth and Earth's Human Carrying Capacity. IN Chapman, A., Petersen, R. & Smith-Moran, B. (Eds.) *Consumption, Population and Sustainability.* Washington DC, Island Press.

Cohen, J. E. (1995) *How many people can the earth support?* New York, W.W. Norton & Co.

Comenetz, J. & Caviedes, C. (2002) Climate variability, political crises, and historical population displacements in Ethiopia. *Global Environmental Change Part B: Environmental Hazards,* 4**,** 113-127.

Corbett, J. (1988) Famine and household coping strategies. *World Development,* 16**,** 1099-1112.

Daily, G. C. & Ehrlich, P. R. (1992) Population, sustainability, and Earth's carrying capacity. *BioScience,* 42**,** 761-771.

Davis, M. (2001) *Late Victorian Holocausts: El Nino Famines and the Making of the Third World,* London, Verso.

Dougill, A. J., Thomas, D. & Heathwaite, A. (1999) Environmental change in the Kalahari: integrated land degradation studies for non equilibrium dryland environments. *Annals of the Association of American Geographers,* 89**,** 420-442.

Dreze, J. & Sen, A. (1989) *Hunger and Public Action.,* Oxford, Claredon Press.

Easterling, W. E., Aggarwal, P., Batima, P., Brander, K., Erda, L., Howden, S., Kirilenko, A., Morton, J., Soussana, J., Schmidhuber, J. & Tubiello, F. (2007) Food, fibre and forest products. IN Parry, M. L., Canziani, O. F., Palutikof, J. P., Linden, P. J. V. D. & Hanson, C. E. (Eds.) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK, Cambridge University Press.

Ely, R. T. & Wehrwein, G. S. (1948) *Land Economics,* New York, Macmillan Company.

Ericksen, P. (2008) Conceptualizing food systems for global environmental change research. *Global Environmental Change,* 18**,** 234-245.

Escobar, A. (1995) *Encountering development: the making and unmaking of the Third World,* Princeton, NJ, Princeton University Press.

Food and Agricultural Organization (2008) *November Food Outlook,* Rome, It, United Nations Food and Agricultural Organization.

Foster, P. (1992) *The World Food Problem,* London, Lynne Reinner Publishers.

Fraser, E., Dougill, A. J., Mabee, W., Reed, M. & Mcapline, P. (2006) Bottom Up and Top Down: Analysis of Participatory Processes for Sustainability Indicator Identification as a Pathway to Community Empowerment and Sustainable Environmental Management. *Journal of Environmental Management,* 78**,** 114-127.

Fraser, E., Termansen, M., Sun, N., Guan, D., Simelton, E., Dodds, P., Feng, K. & Yu, Y. (2008) Quantifying socio economic characteristics of drought sensitive regions: evidence from Chinese provincial agricultural data. *Comptes Rendus Geosciences,* 340**,** 679-688.

Fraser, E. D. G. (2003) Social vulnerability and ecological fragility: building bridges between social and natural sciences using the Irish Potato Famine as a case study. *Conservation Ecology,* 7**,** 9: on line.

Fraser, E. D. G. (2006) Agro-ecosystem vulnerability. Using past famines to help understand adaptation to future problems in today's global agri-food system. *Journal of Ecological Complexity,* 3**,** 328-335.

Fraser, E. D. G. (2007) Travelling in antique lands: studying past famines to understand present vulnerabilities to climate change. *Climate Change,* 83**,** 495-514.

Fraser, E. D. G. & Stringer, L. (2009) Macro forces, micro crises and the collapse of agriculture: Using Romania's landuse history to explore reasons for declines in agricultural productivity. *Global Environmental Change,* 19**,** 45-53.

Global Footprint Network (2008) Earth Overshoot Day. www.footprintnetwork.org/en/index.php/GFN/page/earth_overshoot_day/.

Haddad, L., Hoddinott, J. & Alderman, H. (1997) *Intra-household resource allocation in developing countries,* London, John Hopkins University Press.

Hardin, G. (1968) The Tragedy of the Commons. *Science,* 162**,** 1243-1248.

Hardin, G. (1974) Lifeboat Ethics: the Case Against Helping the Poor. *Psychology Today,* http://www.garretthardinsociety.org/articles/art_lifeboat_ethics_case_against_helping_poor.html**,** Accessed 9th April, 2009.

Hitchcock, R. K. (2002) Coping with Uncertainty: Adaptive Responses to Drought and Livestock Disease in the Northern Kalahari. IN Sporton, D. & Thomas, D. S. G. (Eds.) *Sustainable Livelihoods in Kalahari Environments.* Oxford, UK, Oxford University Press.

Huang, J., Rozelle, S., Pray, C. & Wang, Q. (2002) Plant Biotechnology in China. *Science,* 295**,** 674-676.

Intergovernmental Panel on Climate Change (2007) *Climate Change 2007: Impacts, Adaptation and Vulnerability.,* Brussels, IPCC.

Keopman, J. (1997) The hidden roots of the African food problem. IN Visvanathan, N., Duggan, L., Nisonoff, L. & Weigersma, N. (Eds.) *The Women, Gender and Development Reader.* London, Zed Books.

Lal, R. (2004) Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science,* 304**,** 1623-1627.

Liebig, J. V. (1859) *Naturwissenschaftliche Briefe über die Moderne Landwirtschaft,* Leipzig and Heidelberg, Wintscher'sche Verlagshandlung.

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P. & Naylor, R. L. (2008) Prioritizing Climate Change Adaptation Needs for Food Security in 2030. *Science,* 319**,** 607-610.

Long, S., Ainsworth, E., Leakey, A. & Morgan, P. (2005) Global food insecurity. Treatment of major food crops with elevated carbon dioxide or ozone under large-scale fully open-air conditions suggests recent models may have overestimated future yields. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 360**,** 2011-2020.

Lutz, W., Sanderson, W. & Scherbov, S. (2004) Chapter 2: The End of World Population Growth. IN Lutz, W., Sanderson, W. & Scherbov, S. (Eds.) *The End of World Population Growth in the 21st Century.* London, UK, Earthscan.

Malthus, T. (1976 edition) *An Essay on Population,* New York, Norton Books.

Meadows, D. H. & Club of Rome (1972) *The Limits to growth; a report for the Club of Rome's project on the predicament of mankind,* New York, Signet.

Morse, S. & Fraser, E. D. G. (2005) Making dirty nations clean: The nation state and the problem of selecting and weighing indices as tools for measuring progress towards sustainability. *Geoforum,* 36**,** 625-640.

Murphy, J. M., Sexton, D. M. H., Barnett, D. N., Jones, G. S., Webb, M. J., Collins, M. & Stainforth, D. A. (2004) Quantification of modelling uncertainties in a large ensemble of climate change simulations. *Nature,* 430**,** 768–772.

O'grada, C. (1989) *The Great Irish Famine,* London, Macmillan.

Ostrom, E. (2001) Environment and Common Property Institutions. IN Baltus, H. & Smelser, N. (Eds.) *International Encyclopedia of the Social & Behavioral Sciences.* Oxford, UK, Elsevier Science Ltd.

Ravallion, M. (1994) *Poverty Comparisons,* Paris, Harwood Academic.

Ravallion, M. (1996) Famines and economics, volume 1. Washington, D.C., World Bank.

Rees, W. E. & Wackernagel, M. (1995) *Our ecological footprint: reducing human impact on the earth,* Gabriola Island, New Society Pub.

Rosegrant, M., Meijer, S. & Cline, S. (2002) *International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model description,* Washington DC, International Food Policy Institute. Available on line at: www.ifpri.org/themes/impact/impactmodel.pdf.

Schmidhuber, J. & Tubiello, F. N. (2007) Global food security under climate change. *Proceedings of the National Academy of Science,* 104**,** 19703-19708.

Scoones, I. (1998) *Sustainable Rural Livelihoods: a framework for analysis,* Brighton., Institute of Development Studies.

Seidl, I. & Tisdell, C. A. (1999) Carrying capacity reconsidered: from Malthus' population theory to cultural carrying capacity. *Ecological Economics,* 31**,** 395.

Sen, A. (1981) *Poverty and Famines,* Oxford, Clarendon Press.

Sen, A. (1987) *Hunger and Entitlements: Research and Action.,* Helsinki, World Institute for Development Economics Research (WIDER). United Nations University.

Sen, A. K. (1988) Food Entitlements and Economic Chains. IN Lemay, B. (Ed.) *Science, Ethics and Food.* London., Smithsonian Institute Press.

Simelton, E., Fraser, E., Termansen, M., Forster, P. & Dougill, A. (Available on line) Socio-economic factors that influence agricultural vulnerability to drought: An empirical analysis of three major food crops in China (1961-2001). *Environmental Science & Policy*.

Simon, J. (1981) *The Ultimate Resource,* Princeton, Princeton University Press.

Smith, A. (1998) *An Inquiry Into the Nature and Causes of the Wealth of Nations: A Selected Edition,* Oxford, UK, Oxford Univeristy Press.

Spengler, J. (1971) Malthus and World Hunger. *Proceedings of the Academy of Political Science,* 30**,** 128-142.

Stocking, M. A. (2003) Tropical Soils and Food Security: The Next 50 Years. *Science,* 302**,** 1356-1359.

Stringer, L., Dougill, A., Fraser, E. D. G., Hubacek, K., Prell, C. & Reed, M. (2006) Unpacking participation in the adaptive management of socio-ecological systems: a critical review. *Ecology and Society,* 11**,** 39 [online].

Turner, B. L., Kasperson, R. E., Matson, P. A., Mccarthy, J. J., Corell, R. W., Christensen, L., Eckley, N., Kasperson, J. X., Luers, A., Martello, M. L., Polsky, C., Pulsipher, A. & Schiller, A. (2003) A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America,* 100**,** 8074-8079.

Vetter, S. (2005) Rangelands at equilibrium and non-equilibrium: recent developments in the debate. *Journal of Arid Environments,* 62**,** 321-341.

Watts, M. & Bohle, H. (1993) The Space of Vulnerability: the Causal Structure of Hunger and Famine. *Progress in Human Geography,* 17**,** 43-67.

Watts, M. J. (2000) Development at the millennium: Malthus, Marx and the politics of alternatives. *Geographische Zeitschrift,* 88**,** 67-93.

Woodham-Smith, C. (1962) *The Great Hunger,* London, Penguin Books.

York, R. & Clark, B. (2007) The problem with prediction: Contingency, emergence, and the reification of projections. *The Sociological Quarterly,* 48**,** 713-743.