From Food Production to Food Security:
Developing interdisciplinary, regional-level research

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Abstract

Food security is a condition whereby "*all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life*" (FAO World Food Summit, 1996). Globally, food production has kept ahead of demand for many years, yet about one billion people currently do not have such access. This is due to a combination of biophysical, socioeconomic and political factors. New research concepts, tools and methods are needed to understand, and improve governance of, the complex interactions between these factors if such food insecurity is to be overcome. This is especially the case at the regional (sub-continental) level where many stakeholder groups and actors are involved in setting policies and taking decisions that affect food security outcomes. Based on six publications, this thesis therefore addresses three questions:

What are the essential characteristics of a research agenda to address food security?
Why is research at the regional level important?
Who needs to be involved in research design and delivery, and how are they best engaged?

The food system concept, which integrates an understanding of the activities of producing, distributing, trading and consuming food with the food security outcomes relating to access, availability and utilisation of food, provides a robust framework for analysis of these questions. A synthesis of the publications reveals an effective food security research agenda needs to not only encompass all these activities and outcomes, but also note the range of biophysical, socioeconomic and political food system drivers across and along spatial, temporal and jurisdictional scales. This is because food insecurity arises from vulnerability of the food system to combinations of stresses induced from changes in these drivers. Analysis in this thesis has shown that the ability to overcome these stresses, and thereby enhance food security, would be increased if policy and technical options were considered more specifically at regional level, in addition to at local and global levels. This is however challenging, due to the diversity of stakeholder groups operating at this level (e.g. government and NGOs; researchers and research funders; and business and civil society) all of whom have their own objectives. Further, there are numerous interactions with higher and lower levels on these scales, and insufficient knowledge and awareness of actions taken at these other levels often leads to 'scale challenges'. Participatory research methods (e.g. surveys, consultations and scenario exercises) have been found in this research to help overcome these 'scale challenges'.

Improved understanding of how food systems operate will help food security planning by identifying where, when and how vulnerability arises; and hence what sorts of adaptation interventions are needed, and where and when they would be most effective. Understanding can be enhanced by integrating concepts from production ecology, agroecology and human ecology with concepts of food systems and scales, to develop the notion of 'food system ecology'. This not only helps identify the many biophysical and socioeconomic interactions across the range of activities and drivers that determine food security, but also provides a framework for two key research avenues: increasing the efficiency with which inputs to the food system are used, and enhancing food system governance.

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Part I: Background and introduction

Food security concepts and the need for an holistic view

Food is a fundamental human need. Our efforts to secure food have been intimately interwoven with the evolution of many societal structures such as our laws and regulations, our customs and ceremonies, and our trade and commerce arrangements. In addition to serving nutritional needs, food is an important factor in cultural identity; food can reveal relationships between the past and the present, reflect epochal transformation, and mark changing identities of various groups of people through new ways of appropriations (Chan, 2010).

For many people today, and historically for the vast majority, efforts to secure food have dictated our everyday activities of hunting, gathering, farming, ranching and fishing. Such efforts have also driven the way we have exploited (and often over-exploited) natural resources. The demand for food has been the main driver of land conversion (70% of mediterranean forests, 60% of temperate broadleaved forests and 70% of tropical forests have been converted to agricultural/grazing land; MA, 2005a) and fisheries declines (25% of major fisheries have collapsed over the last 50 years; Mullon et al., 2005).

Driven by the requirement to feed ever increasing human demand, major scientific and technical advances have been made in the production of food. Based on a series of research, development, and technology transfer initiatives occurring between the 1940s and the late 1970s, the 'green revolution' saw agriculture production increase around the world. Rapid advances were seen initially in Mexico, the US and Europe, and then in Asia (Hazell, 2009). Many developments were also seen in animal sciences and in fisheries. Globally, food production has kept ahead of demand for many years, and today more than enough food is produced to feed the global population (Dyson, 1996; Ingram and Lang, unpublished): 219 kg of grain is needed annually to meet basic caloric requirements of 2,100 calories per day *per capita* (Palm et al., 2010); 2250 Mt of grain was produced in 2009/10 (USDA-FAS, 2010) equating to approximately 325 kg annually *per capita*. Increasing production, initially though extensification and more recently through intensification (Gregory et al., 2002), has clearly been an effective strategy for producing food. Indeed, food supply has been so good for many that increasing levels of obesity had already become a problem worldwide by the close of the last century (Dyson, 1996), although the trend is now levelling in the US (Flegal et al., 2010). But, despite this success in maintaining food production ahead of *per capita* need on a global basis, history shows that increasing production alone does not satisfy food security for all: in

2010 about 925 million people had to go to bed hungry (FAO, 2010). Production alone is manifestly not the only factor. Increasingly, and especially since the 1996 World Food Summit (FAO, 1996b; FAO, 1996a), the notion of food security is not so much one of food production but more relates to access to food. A further dimension is the nutritional content and, if one also includes the fact that some two billion people are iron-deficient worldwide, the 2010 FAO estimate of 925 million food-insecure is a gross underestimate (Pinstrup-Andersen, 2009).

Food security is a state or condition. It is a flexible concept as reflected in the many attempts at definition in research and policy usage (FAO, 2003), and numerous definitions of food security thus exist. Even by 1992 Maxwell and Smith had counted over 200 (Spring, 2009), and more are still being formulated (e.g. Defra, 2006). Nonetheless, a commonly-used definition stemming from the 1996 World Food Summit states that food security is met when "*all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life*". This definition built on the key work by Amartya Sen (Sen, 1981) in which he demonstrated that famine occurs not only from a lack of food, but from inequalities built into mechanisms for distributing food. So, not only does the definition bring in a wide range of issues related to a fuller understanding of food security, but some key words such as "food production" and "agriculture" – which might have been expected in such a definition – are *not* included; the emphasis changed from increasing food production to increasing access to food for all.

The majority of more recent definitions of food security share the notion of access to food as being the key aspect. These definitions are manifestly valuable in raising the profile of the many factors that contribute to food security in addition to producing food. The nutritional and food safety dimensions of food feature explicitly, as do the roles of wealth and food prices which underpin the fundamentally-important notion of 'affordability' ("economic access"). Other dimensions are more implicit: the notion of "preferences" implies not only what we like to eat, but also the function food plays in, for instance, our social and cultural norms. The idea of "all people, at all times" implies both equitable allocation within society and stability of sufficiency. Further, although again not explicit in the definition, spatial levels higher than the agricultural plot are implied: "physical access" introduces the critically important issues of proximity, storage and distribution which in turn indicate the importance of food trade locally and internationally.

From an 'industrialised world' viewpoint, the notion of food security (or more correctly, food *in*security) has long been associated with 'developing world' issues, and has hence been the purview of development agencies, rather than government departments and other national agencies concerned with domestic agendas. Indeed, until recently, 'food security' has not been a priority policy topic in the industrialised world and in the UK, for instance, few – if any – government documents since the Second World War included the phrase 'food security' in the title. Recently, however, there has been a growing realisation of the scale of future requirements: 50% more food will be needed by 2030, and possibly 100% more meat by 2050 (Godfray et al., 2010b). This, coupled with the 2007-08 food price spike which saw the number of hungry people leaping 40 million in a few weeks to exceed 1 billion (FAO, 2008b) has led to renewed concerns about hunger; the notion of food security has taken centre stage in many fora. While a few argue that the world will be quite capable of feeding the predicted 2050 population of nine billion people (e.g. Paillard et al., 2011; *The Times*, 14 January 2011), the majority view is that this is by no means certain in a sustainable manner. Food security concerns have hence rapidly ascended policy, societal and science agendas in many countries and have been the topic of special issues of leading scientific journals (e.g. *Phil. Trans. R. Soc. B*, 2010 vol 365; *Science*, 2010, vol 372), government documents (e.g. Defra, 2009; USDA-ERS, 2009) and leading high-circulation media such as the *Economist* (21 November 2009) and *Time* (26 October 2009).

Almost overnight governments began issuing statements about food security (in contrast to agricultural development and food production) and the media relayed these to civil society, enhancing political interest. In their July 2009 joint statement, for instance, the G8 heads of state agreed "to act with the scale and urgency needed to achieve sustainable global food security" (G8, 2009). Calls from research funders echoed these sentiments and 'food security' is now commonly seen in the titles of research proposals, papers, books and other science outputs. Importantly, however – and despite the high-level nature of the 1996 World Food Summit, and with it the much more holistic understanding of what is entailed in food security – a large proportion of the discussion under this banner continues to address issues related to food production rather than the broader food security concept. When addressing food security, it is crucial to take a broad view. This will of course include the fundamentally-important part that producing food plays, but discussions must not be restricted to this narrow view; the impact of the 2007-08 food price spike underscored the concept of economic access to food being critically important, rather than food supply *per se*.

An historical emphasis on food production research

The food production aspects of food security have long been the subject of major scientific research investment. In 1843 the Rothamsted Experimental Station was established in the UK, while the latter part of the 19th century saw the rapid growth of commercial plant-breeding in Germany (Harwood, 2005). Despite these many years' research, there is still a need to establish how to produce more food given anticipated demand (Royal Society, 2009). However, satisfying these increased demands poses huge challenges for the sustainability of both food production, and the terrestrial and aquatic ecosystems and the services they provide to society (Tilman et al., 2002).

Conscious of the negative environmental consequences of most current food production methods, it is clear that the necessary gains will have to be made in a more environmentally-benign manner (Gregory and Ingram, 2000; Foresight, 2011). To this end, research has increasingly focused on the production *system* (rather than just on the plant or animal component) seeking to increase the efficiency by which inputs (especially nitrogen and water) are used, and reduce negative externalities such as soil degradation, water pollution, loss of biodiversity and greenhouse gas emissions (van Ittersum and Rabbinge, 1997; Gregory et al., 2002).

Meanwhile, as the climate change agenda has gathered momentum, research on the impacts on food production has rapidly increased. It is now clear that climate change will affect crop growth in many parts of the world, with the most deleterious impacts anticipated in the developing world (Parry et al., 2004; Parry et al., 2005; Foresight, 2011). Changes in average temperatures, and in rainfall amounts and patterns will have positive and negative effects on yields and/or change production costs, depending on location, but increases in weather extremes are particularly worrying: an increase in double droughts or prolonged elevated temperature at critical stages of crop growth will be locally devastating and of major concern if widespread. Livestock and fisheries will be affected both directly through heat stress and indirectly through impacts on grazing and other feed stocks. Climate change will also have indirect impacts on food production through alterations to pests and diseases, and on demands for water. Negative impacts on crops will only be marginally offset by the fertilisation effects of elevated CO_2, with perhaps a 8-12% gain for a double pre-industrial CO_2 concentration (Gregory et al., 1999); but a world with such elevated CO_2 would experience such massive climate change that all efforts must be made to avoid this.

While agricultural research is moving towards addressing the twin goals of producing more food while simultaneously reducing negative environmental feedbacks (or even increasing positive environmental feedbacks e.g. though carbon sequestration), a major motive for most such research remains the need to increase food production yet further. This research effort has gained impetus from the increasing realisation of the (mainly) detrimental impacts that climate change and other aspects of global environmental change (GEC; e.g. changes in water resources, biodiversity, tropospheric ozone, sea level) will have on food production, most notably in the developing world. This is based on a greatly increased understanding of how GEC will affect food productivity (yield) at field level.

Emergence of more integrated food security research

The continuing research emphasis on producing food is not surprising given its long-established momentum and on-going investment, and the undeniable need of having to produce more food in the years ahead. But, despite the fact the world currently produces enough food for all, the number of food-insecure people world-wide currently attests that our understanding and approaches are insufficient. New concepts, tools and approaches are clearly needed to address the broader food security agenda. Their development is all the more urgent given the additional complications that GEC is already bringing to the many for whom food security is already far from easy. Yields are now seen to be deleteriously affected by rising temperatures (Lobell et al., 2011); increases in the frequency of floods and droughts (although hard to attribute to climate change *per se*, but which are widely anticipated in future climate scenarios) disrupt food storage and distribution systems (as vividly seen in Pakistan in 2010), and contribute to raising food prices on the international markets (as seen following the Australian drought also in 2010).

So how has research aimed at encompassing a broader food security agenda developed?

The economics and social science research communities have been addressing the broader perspectives on food security for several decades. Socioeconomic aspects have been an important component of farming systems research since the early 1970s, and Duckham and Masefield (1970) noted that the relevance of research and technology to any farming system can only be assessed with a knowledge of both the ecological and economic factors operating on that system. Since the World Food Conference in 1974 researchers have been interested in livelihoods at household and individual levels, an important determinant of food security given the need of many to buy food (Maxwell, 1996), while more recent work has studied the role of food prices (e.g. Johnston, 1984; FAO, 2009a) and institutions (e.g. Maxwell, 1995; Karanja, 1996).

These developments were however largely uncoupled from research by the biophysical community but, given the multiple dimensions of food security, the need for interdisciplinary, even trans-disciplinary, approaches is now well accepted (Liverman and Kapadia, 2010; UK Global Food Security Programme, 2011). Indeed, food security research is in fact a very good example of the need for much enhanced interdisciplinarity, with social science, economics and the humanities all playing critical roles in addition to the biophysical sciences (Pálsson et al., 2011), and accepting this acknowledges contributions of many different disciplines.

Early work by the GEC research community on food security recognised the need to think broadly (as distinct to limiting work on crop productivity), and initially addressed the notion of 'food provision' (Ingram and Brklacich, 2002; Ingram and Brklacich, 2006: **Paper 1**). This work embraced the important notion that food provision[1] is governed by both the availability of, and access to, food. Access to food was noted as a function of economic potential, physiological potential (e.g. nutritional quality) and food availability. Food availability depends on production and distribution, with food production being a function of yield per unit area and the area harvested.

Yield per unit area (or productivity) is a function of genetic potential (G), environment (E) and management (M). This approach is particularly useful in stressed environments (Spiertz and Ewert, 2009) and it is hence the "E" component which has attracted the considerable interest of GEC researchers given that GEC is usually associated with increased biophysical stress. (It is worth noting that the bulk of the GEC 'food' literature addresses crops, and hence the notion of crop yield, hectares under cropping, etc. dominates; livestock and fisheries have some prominence, 'wild food' hardly any.)

[1] The term 'food provision' was later dropped in favour of 'food security' so as to move away from the notion of providing food and towards the notion of access to food encapsulated in the FAO 1996 definition.

While the flow of the argument about how GEC will affect food security via impacts on crop growth is thus relatively easy to define, the flow back to how this will affect regional production, thence availability, and thence provision is far from simple. This is because many other factors emerge which govern these parameters. For instance, even the extrapolation of point results to estimate regional production is not straightforward due to a range of genotypes and management practises employed and landscape heterogeneity (Ingram et al., 2008: **Paper 2**). Significant advances are however now being made in modelling regional production (e.g. Challinor et al., 2007; Thornton et al., 2011). Even if changes in regional production are established, assessing how this will affect food security within the region and beyond is highly complex due to wide range of socioeconomic factors such as demography, wealth, prices, customs and intra- and inter-regional trade arrangements that all affect access to food.

The Global Environmental Change and Food Systems Project (GECAFS)

The interdisciplinary notion of food security was further developed within an internationally-agreed research project (Global Environmental Change and Food Systems, GECAFS, 2001-2011) under the auspices of the international GEC research community (Gregory et al., 1992). The goal of GECAFS was "*to determine strategies to cope with the impacts of global environmental change on food systems and to assess the environmental and socioeconomic consequences of adaptive responses aimed at improving food security*" (Ingram et al., 2005).

GECAFS planning identified four issues of particular interest because they would set the context for many researchable questions (Ingram et al., 2005). First was the need to better understand what constitutes vulnerability to GEC in relation to food security. This would be key to helping to determine where, when and which sections of society are most at risk, and was especially necessary given problems of predicting global food production (Döös, 2002). Second was the need to construct scenarios of future conditions that encapsulate the socioeconomic and biogeophysical factors that determine food security. Third was the need to assess options for reducing the vulnerability of food systems to GEC. Fourth was the need to understand how best to report and communicate research results and so help devise improved policies to adapt food systems to GEC.

Developing 'food systems' research

Akin to the need for adopting the broader concept of food security (rather than just food production), it was also recognised that research planning and policy formulation to address this challenging goal needed to be set within the context of food systems, rather than just food supply. The term "food systems" was chosen for the GECAFS focus (and hence is used in the project title) rather than "food security" as it was recognised that it is food systems that underpin food security and that defining the system clearly would provide a structured, analytical lens to research the highly complex food security agenda.

Developing research in the context of food systems helped to identify and integrate the links between a number of activities "from plough to plate" (Atkins and Bowler, 2001), including producing, harvesting, storing, processing, distributing and consuming food. But it was also realised that research on these activities alone was insufficient: an innovative, interdisciplinary framework was needed that combined this with work on the consequences (or outcomes) of the activities for the well-established food security components of *food availability*, *access to food* and *food utilisation*, all of which need to be stable over time (FAO, 1996b). The development of a conceptual framework also helps to bridge disciplines, showing where each contributes. Further, it is also especially valuable when devising management interventions, development strategies and policies (Thompson et al., 2007) by identifying the range of issues stakeholders involved in food security discussions need to address.

GECAFS research towards this framework culminated in the 'GECAFS Food System' concept (Ericksen, 2008a; Ingram, 2011: **Paper 3**). Drawing on earlier food system approaches (e.g. Sobal et al., 1998), this integrated framework provided a structured approach to GEC-food security research, with particular emphasis on interactions with GEC drivers and vulnerability (Ericksen, 2008b). The vulnerability aspects was further refined to clearly differentiate the vulnerability 'of what' (i.e. the food system; Eakin, 2010) from the 'to what' (i.e. to combined socio-economic/GEC drivers; Misselhorn et al., 2010); vulnerability debates can be nebulous without clearly stating vulnerability of what, to what.

Multiple scales and levels, and multiple stakeholders

In addition to realising the need for a broad food systems approach, it was also realised that this needed to be implemented at regional level. This was because it was noted that considerable GEC-food production research had been conducted at local (i.e. plot) level (and which has subsequently formed the substance of many reviews and syntheses (e.g. Fuhrer, 2006; Easterling et al., 2007), and several major studies had also been conducted at global level (e.g. Parry et al., 1999), but little information existed in between local and global levels – i.e. at the regional level.

This realisation shaped the original charge by the GEC Programmes to the international GEC research community to move beyond the local-level, production-orientated research that had characterised international GEC 'food' research thus far (Gregory et al., 1999); an innovative international research project was needed not only to address food security in a broader sense (including stability over time), but also to undertake research at the 'regional' (i.e. sub-continental) level (Ingram et al., 2005). Multi-scale, multi-level approaches were needed, where 'scale' is the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon, and 'level' is the units of analysis that are located at different positions on a scale (Gibson et al., 2000; Cash et al., 2006). GEC and food security issues span a number of different scales (e.g. spatial, temporal, jurisdictional, institutional, management) and a number of levels along each of these scales (e.g. national, regional; days, seasons) (Ericksen et al., 2010a). Social, economic, cultural and political factors largely determine interactions along and between scales, and understanding the interactions between and within them are critical to understanding the controls on food security.

Recognising that an analysis of existing approaches and strategies for food security at regional levels was lacking (Liverman and Ingram, 2010: **Paper 4**), GECAFS development therefore concentrated on how to integrate environmental and socio-economic drivers and outcomes at this spatial level. The specific GEC angle led to considerations of what adaptation measures could enhance food security by reducing food system vulnerability to GEC at regional level, while also minimising further environmental degradation. Many technical considerations apply at local level, especially concerning producing food (e.g. enhanced agro- and aquaculture technologies), while others pertain to the regional level (e.g. rail infrastructure in relation to food distribution). Much of the debate at the regional level is however in the policy arena. This led first to issues of who was the intended policy 'client' for outputs from such research at this spatial level; and second to the question of how best to engage them in co-designing the research agenda so as to ensure the research outputs would be of most value to them (Ingram et al., 2010: **Paper 5**). Given the lack of regional-level studies (in relation to global and local), this focus opened up novel ways of formulating GEC/food security research.

As understanding grew about how the whole food system operates (as opposed to the agricultural component alone), it became increasingly clear that numerous actors operate across a wide range of scales and levels. Further, the role of 'non-state actors' is becoming increasingly important worldwide (Schilpzand et al., 2010) and the need for engaging these stakeholders (i.e. beyond the research and regional policy communities) became apparent. The challenge is how to integrate these various considerations when undertaking GEC-food security research at regional level (Ingram and Izac, 2010: **Paper 6**).

Specific challenges the thesis addresses (thesis questions)

Much progress had been made in conceptualising the GEC-food security issues and research agenda during intensive GECAFS planning exercises. However, turning these ideas into practice posed a number of major challenges the GEC research community had thus far not experienced, especially as it encompassed a number of food system activities beyond producing food. These related to issues such as which disciplines should be involved and how should interdisciplinary research best be developed; what the optimum spatial and temporal resolutions should be, and who should be involved in research design, when and how; identifying the 'client', and how interactions with them should best be managed; and, importantly, how research would best build on – and contribute to – improving understanding of GEC-food security interactions. Embarking on the full system approach therefore necessitated a somewhat different approach to designing and implementing international GEC research projects than those which had hitherto been designed by researchers on more disciplinary topics (Ingram et al., 2007b).

This thesis addresses these issues by distilling them into three questions:

1. What are the essential characteristics of a research agenda to address food security?

2. Why is research at the regional level important?

3. Who needs to be involved in research design and delivery, and how are they best engaged?

These questions are addressed by drawing on a set of six papers published over recent years and synthesising the main elements of each to help promote innovative and effective food security research for the future.

Thesis structure, the six papers and why they have been selected

The thesis comprises this Introduction, the six papers and a Conclusion.

This Introduction (**Part I**) sets the papers in context by discussing the need for, and emergence of, more integrated food security research over the last decade, and lays out the specific challenges the papers address.

Part II comprises the first set of three papers which describe the development of a more integrated approach to food security research:

Paper 1: Global Environmental Change and Food Systems

This covers food provision and interactions with the environment. It introduces initial food systems concepts and couples these with emerging food system vulnerability concepts. It also considers the nature of GEC impacts on food systems, the nature of adaptation options and the need to consider feedbacks from such options to both socioeconomic conditions and environment, highlighting the need for tools for trade-off analyses.

Paper 2: The role of agronomic research in climate change and food security policy

This paper lays out the need to better understand how climate change will affect cropping systems. It identifies the need both to assess technical and policy adaptation options and to understand how best to address the information needs of policy makers. It covers the importance of spatial scale and the position of crop production in the broader context of food security.

Paper 3: A Food Systems Approach to Researching Food Security and its Interactions with Global Environmental Change

This paper lays out the food system concept differentiating clearly between food system *Activities* and food security *Outcomes*. It includes a number of examples of when, how and why a food system approach helps in understanding and framing food (in)security research. Examples include (i) analysing the vulnerability of food systems to GEC and identifying food system adaptation options; (ii) analysing the consequences of interventions on food security outcomes; (iii) food system concepts for framing scenarios analyses; (iv) quantifying the contribution of food system activities to crossing ‘planetary boundaries’; and (v) analysing the food security dimension in international environmental assessments.

Part III comprises a further three papers and makes the case for regional-level research and broad stakeholder engagement:

Paper 4: Why regions?

This paper introduces Part III by discussing why the regional level is important for food systems and food security/GEC research. It argues for moving research from local to regional, highlights the range of cross-scale and cross-level interactions that determine food security and gives some example of “scale challenges”.

Paper 5: Engaging stakeholders at the regional level

This paper identifies who the stakeholders are in the GEC-food security debate, and thereby who needs to be involved in setting the GEC-food security agenda. It discusses when to engage stakeholders in research planning and how, and identifies elements of good practice in stakeholder engagement. It also discusses different types of interactions with stakeholders so as to enhance decision support for food security and how to assess the effectiveness of such engagement.

Paper 6: Undertaking research at the regional level

This final paper brings together the previous papers by ‘translating’ theory into practice at the regional level. It starts by discussing how to identifying the ‘client’ at this spatial level. It then describes how to encourage regional research networks and the importance of team building and adopting standardized methods. It concludes by laying out some methodological challenges for food systems research at the regional level including funding issues and how to establish institutional buy-in.

Building on this set of published work, **Part IV** (Reflections and Conclusion) explains why the thesis title and thesis questions are appropriate, and how the papers address the questions.

It then systematically explores the three questions above, discussing the importance of this type of research and its impact on the science agenda, including developing the notion of ‘food system ecology’ and its contribution to policy development. Finally it outlines important future research needs and considers the nature of the international science institutions and new partnerships necessary to support these.

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Part II: The development of an integrated approach to food security research

Paper 1: Global Environmental Change and Food Systems

Adapted from:

Ingram, JSI and M Brklacich. 2002. Global Environmental Change and Food Systems (GECAFS). A new, interdisciplinary research project. *Die Erde* **113**, 427-435.

and

Ingram, JSI and M Brklacich. 2006. Global Environmental Change and Food Systems. pp 217-228. In: E Ehlers and T Krafft (Eds). *Earth System Science in the Anthroposcene*. Springer-Verlag, Berlin.

Paper 2: The role of agronomic research in climate change and food security policy

Adapted from:

Ingram, JSI, PJ Gregory and A-M Izac. 2008. The role of agronomic research in climate change and food security policy. *Agriculture, Ecosystems and Environment* **126**, 4-12.

Paper 3: A Food Systems Approach to Researching Food Security and its Interactions with Global Environmental Change

Adapted from:

Ingram, JSI. 2011. A Food Systems Approach to Researching Food Security and its Interactions with Global Environmental Change. Re-submitted with revisions to *Food Security* on 3 June 2011

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Introduction: Food Provision and the Environment

Food is fundamental to human well-being. Improved methods are needed to grow, harvest, store, process and distribute food as societal demand for agricultural and fisheries products increases, and in many parts of the world economic and social development is often mediated by food constraints at local and regional levels.

Links between food systems and the environment are well-documented. Environmental factors such as climate, soils and water availability have long been recognised as major determinants of the ability to produce food in a given location, and a wide range of farming and fishing strategies have been developed in response to the differing environmental conditions around the world. The production, processing and distribution of food however have considerable impacts on environment by, for instance, altering biodiversity, emitting green-house gases, and degrading soils and other natural resources by over-exploitation and pollution. This close, two-way relationship with environment exerts considerable influence on production and – ultimately – on the availability of, and accessibility to, food.

Until recently, the effects that food systems have on environment were perceived at relatively local spatial scales. For example, soil erosion caused by intensive crop production resulted in the siltation of nearby water courses, and contamination of ground and surface water supplies by agricultural chemicals did not reach beyond local water sources. However, human activities – in considerable part due to satisfying the need for food – are now recognised to be changing the environment over large regions, and even at global level. Overall these macro-scale changes can be divided into two broad categories. One involves fundamental changes to major earth systems and functions which operate at the global level, such as climate and the cycling of nitrogen. The other involves incidences of environmental change at the local level which are so widespread as to be considered global phenomena; degradation of fresh water resources and soil erosion have, through their collective extent, transformed from local concerns and are now issues that must be considered and addressed over large regions. Collectively these changes are termed “Global Environmental Change” (GEC). GEC will bring additional complications to the already difficult task of providing sufficient food of the right quantity and quality to many sections of society. Improving food provision in the face of GEC, while at the same time minimizing further environmental change, is a crucial issue for both development and society at large.

Food Provision and Food Systems

Recent years have seen a greatly increased understanding of how GEC will affect food productivity at field level, and research results pave the way for broader analyses of GEC impacts on food production on a regional basis. However, there is a need to think beyond productivity and production – of ultimate interest is food provision, a concept of greater relevance to society well-being and hence policy making.

A wide range of sciences are needed to address the components of the “Food Provision Equation” (Box 1): estimates of food production are founded in agroecology, agriculture and fisheries sciences, while issues related to distribution are largely researched by social and policy-related sciences. The broader notion of access requires consideration of a further set of disciplines including economics, sociology and nutritional sciences.

Box 1 Food provision

Food provision is governed not only by production, but also by the availability of, and access to, food. Access to food is a function of economic potential, physiological potential (e.g. nutritional quality) and food availability (which depends on production and distribution). Food production is a function of yield per unit area and the area from which harvest is taken.

Production	=	*f* (yield, area)
Availability	=	*f* (production, distribution)
Access	=	*f* (availability, economic & physiological potential)
Food Provision	=	*f* (Production, Availability, Access)

Akin to the need for adopting the broader concept of food provision (rather than just food production), research planning and policy formulation needs to be set within the context of *food systems*, rather than just food supply. Developing research in the context of food systems helps to identify and integrate the links between a number of factors “from plough to plate” (Atkins and Bowler, 2001), including consideration of production, harvesting, storage, processing, distribution and consumption. The approach thereby allows a more thorough understanding to be developed of the “impacts” and “feedbacks” links between food provision and environment. It will also help to identify where technical and policy interventions might be most effective to (i) cope with short-term impacts of GEC; and (ii) help adapt for environmental conditions in the longer term. Coping and adaptation strategies for food provision will however need to differ depending on the degree to which people and communities are vulnerable to the impacts of GEC. Not all individuals and sections of society are equally vulnerable to GEC; their capacity to cope with existing variability in biophysical and socioeconomic systems, and their ability to perceive GEC and adapt food systems accordingly vary considerably. This is because these factors are controlled by the flexibility with which the supply, availability and access to food (and related, essential resources) is mediated by socioeconomic institutions such as land tenure, access to credit, exploitation rights of renewable resources, etc.

Adaptation strategies will need to encompass both biophysical and policy options. Management decisions must however be underpinned by a sound understanding of both the socioeconomic and environmental consequences that different possible strategies will bring.

GECAFS: A New Research Approach

The interactions between global environmental change and food provision involve many complex issues spanning natural, social and climate sciences. The International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP) and the World Climate Research Programme (WCRP) already encompass broad research agendas in these three major areas. However, in order to advance our understanding of the links between GEC and food provision (and thereby help to develop and promote effective interventions) IGBP, IHDP and WCRP have launched the Global Environmental Change and Food Systems (GECAFS) Joint Project as a new, interdisciplinary approach. Furthermore, the research agenda is broader than impact studies alone (important though these continue to be) as it explicitly includes research on how food provision systems could be adapted to the additional impacts of GEC, and the consequences of different adaptation strategies for socioeconomic conditions and environment. By including both "impacts" *and* "feedbacks" in the context of food provision a niche for new research is clearly defined.

GECAFS has been conceived to address issues of interest to development, to society at large, as well as to science. An innovative, three-way dialogue between policy-makers, donors and scientists is being established to develop specific research agendas which are useful to aid policy formulation, scientifically exciting and fundable. Many research groups are active in the general area of food "security" but their activities generally focus on *current* impediments to food production. Building on on-going studies but emphasising GEC issues, and linking closely to the needs of policy formulation, the structured approach will deliver an efficient research mechanism to address the rapidly emerging "GEC-Food" agenda. Of ultimate interest is the link between GEC and societal well-being (rather than with food systems *per se*). This however has to be addressed through the researchable issues needed to understand the relationships between GEC and food systems and it is this that requires the innovative, interdisciplinary approach.

GECAFS Goal and Science agenda

The GECAFS goal is to determine strategies to cope with the impacts of Global Environmental Change on food provision systems and to analyse the environmental and socioeconomic consequences of adaptation.
Research is being developed as three, inter-related Science Themes (see Figure 1).

Theme 1: Vulnerability and Impacts: Effects of GEC on Food Provision
Theme 2: Adaptations: GEC and Options for Enhancing Food Provision
Theme 3: Feedbacks: Environmental and Socioeconomic Consequences of Adapting Food Systems to GEC.

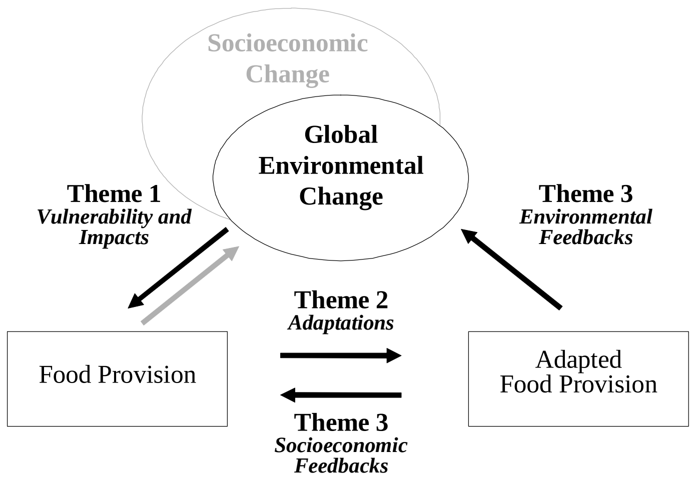

Figure 1 A diagrammatic representation of the three GECAFS Science Themes with respect to GEC and food provision systems. The contextual issues of changing socioeconomic conditions and the consequences of current food provision systems on GEC are depicted in grey, while the main features of GECAFS are shown in black.

Theme 1 "Vulnerability and Impacts"

Theme 1 research is set within the context of the question "Given changing demands for food, how will GEC additionally affect food provision and vulnerability in different regions and among different social groups?". This question recognises that many factors already affect food provision and vulnerability, and that these are posing different stresses. It however raises the issue that GEC may well bring further complications – hence the word "additionally" – and further recognises that vulnerability to GEC varies for different food provision systems, and hence will have differing impacts among different social groups.

Food provision is controlled by a range of biophysical and socioeconomic factors working interactively at a range of temporal and spatial levels. These factors ultimately determine the vulnerability of food systems to both biophysical and socioeconomic change (see Figure 2). Biophysical factors include climate, weather and site-related natural resources (e.g. soils, topography, water availability, previous vegetation and site management, distribution of exploited fish populations, coral reefs); socioeconomic factors include current agricultural, aquaculture and fisheries management (e.g. germplasm selection, timing of operations, nutrient and pest management), population density and demand for food products (for local consumption and trade), availability (markets, distribution, storage) and access (e.g. socio-political controls, exploitation rights, equity, wealth). Research will therefore address constraints and opportunities for meeting future demands for food from several perspectives including aggregate regional supply and demand, and broad-scale socio-economic conditions which either threaten or promote food accessibility. Theme 1 will identify where GEC will be particularly important and why, and also examine the crucial issue of vulnerabilities and impacts of GEC on regional food production potential.

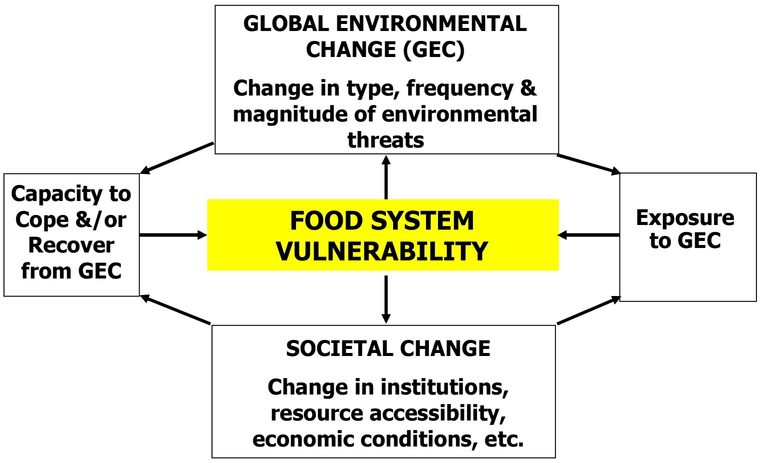

Figure 2 Food system vulnerability in the context of global environmental and societal changes (derived from Bohle, 2001; McMichael and Githeko, 2001).

Theme 2 "Adaptations"

Theme 2 deals with the basic question "How might different societies and different categories of producers adapt their food systems to cope with GEC against the background of changing demand?". This question recognises that within given societies not all people and groups will be equally able to adapt to changing demands for food, and that adaptation strategies to cope with the additional complication of GEC will vary; different groups will have different limitations to adaptation.

Theme 2 aims to understand how communities and institutions might anticipate, resist or adapt to, and recover from the impacts of GEC. GEC may cause food provision problems in the short term, when adaptations mechanisms are too slow, and in the long term, where adaptation mechanisms are simply not effective. Research needs to concentrate on how environmental and socio-economic forces combine at local to regional levels either to enhance or reduce vulnerability; on existing strategies for coping with food shortages; and on the extent to which global environmental and socio-economic forces might alter human vulnerability within selected regions. To make these assessments will require the identification of the most vulnerable groups, the key institutions in society that make or break coping and adaptation efforts, and management efforts which will be needed to counteract the negative aspects of GEC. The nature of critical thresholds for adaptation, and when and where these will be exceeded will be a critical part of the research agenda. In addition, it will determine the speed of coping and adaptation that different groups in society possess, and how this relates to GEC.

Theme 3 "Feedbacks"

The third theme considers "What would be the environmental and socioeconomic consequences of alternative adaptation strategies?" The question recognises that different adaptation strategies will have different consequences for both socioeconomic systems and environment, and that both types of consequence are equally important and need to be considered simultaneously. Theme 3 will allow regional-level analyses of "tradeoffs" between socioeconomic and environmental issues for a range of management and policy options. These analyses will be conducted within the scenarios agreed upon in the project planning phase.

Research will need to develop tools to identify, and quantify as far as possible, the feed-backs to environmental issues such as atmospheric composition and other climate change drivers, consequences for biodiversity and land and aquatic degradation, and also to socioeconomic issues such as livelihoods, institutional flexibility and policy reform. The rapidly growing concern for potential environmental degradation due to changes in genetic variability and biotechnology will be included.

By complementing work in Themes 1 and 2, this "feed-backs" component will identify GECAFS as a comprehensive GEC research programme.

The GECAFS Science Themes provide an innovative framework within which new areas of science can be developed and harnessed to address societal concerns. Examples include:

- Methods for the analysis of environmental and socioeconomic tradeoffs in food systems.

- Analyses of changing human wealth and food preferences and interactions with biophysical models of GEC to produce new insights of regions where food provision may be sensitive to GEC.

- Methods to allow the appropriate level of aggregation of small-scale food production systems and disaggregation of global-scale scenarios and datasets to address regional and sub-regional issues.

- New analyses and insights into the institutional factors which can reduce societal vulnerability to GEC.

- Developing combined socioeconomic-biophysical indices of vulnerability.

GECAFS studies will need to be set within clearly defined sets – or “scenarios” – of future biophysical and socioeconomic conditions. These will be specifically designed to assist analysis of possible policy and biophysical interventions using the interdisciplinary science at the Project’s core, and will set the context for the individual research projects. They will help to “tease out” the meaning of “socioeconomic change” in the context of GEC. The development of these comprehensives scenarios is in itself a major research exercise. This has been initiated by defining three broad categories of attributes as a minimum set of required contributing data: the food system; socioeconomic and demographic factors; and environmental and ecological data. The further development of “aggregated indicators” to assess vulnerability will be a significant new science output.

Research Design, Implementation

GECAFS aims to help strengthen policy formulation for reducing vulnerability to global change at national to sub-continental scales; and to provide tools and analyses to undertake assessments of trade-offs between food provision and environment in the context of global change. To be effective research will be developed that meets the needs of national and regional policy makers, the principal “clients” for GECAFS research. GECAFS will therefore engage with policy makers early in the research planning process to develop research that directly addresses their needs and maintain close links throughout the implementation and reporting phases. In collaboration with research partners and collaborators, donors and end-users, GECAFS will (i) identify interdisciplinary research topics of mutual interest to science, development and policy formulation; (ii) help in developing databases and future scenarios to explore tradeoffs; (iii) help in the dissemination of results and obtaining feedback from end-users; and (iv) assist in capacity building as part of its research approach.

GECAFS research will thus be implemented in two major ways: (i) *Individual GECAFS projects* at sub-continental-level, “tailor-made” to address particular interests of policy makers, donors and science community; and (ii) *Integrative GECAFS studies* at multi-region to global level, which integrate individual studies. Individual studies will undertake research address all three science themes.

GEC and the Food System of the Indo-Gangetic Plain: An Example GECAFS Research Project

One of the initial regional GECAFS research projects concerns the food system of the Indo-Gangetic Plain (IGP). This is largely dependent on rice and wheat grown in rotation and there is growing concern that the productivity of the system is declining, especially the rice component: an assessment of 11 long-term rice-wheat experiments (ranging from 7 to 25 years in duration) from the region indicates a marked yield decline of up to 500 kg/ha/yr in rice in nine of the experiments (Duxbury et al., 2000). Continuation of these trends will have serious implications for food provision, local livelihoods and the regional economy. As a given season's weather is a major determinant of yield (due to both the direct effects on crop growth and indirect effects related to management), there is concern that changes in climate, especially related to changes in climate variability, will exacerbate the observed trend. Moreover, other analyses (e.g. Grace et al., 2001) show that the highly-intensive production approach currently practiced in large parts of the region is a major source of greenhouse gases, while the current irrigation practice is having serious negative effects on local water tables and water quality.

As the IGP food system is both threatened by global change and contributes to further global change "forcing", research is needed to help develop policy and agronomic strategies to (i) sustain production, especially in the face of potential increased climate variability and degradation of land and water resources; and (ii) promote production systems which enhance environmental and socioeconomic conditions. Due however to the marked socioeconomic and biophysical differences across the region, a single approach is not appropriate. A consultation process with local and regional policy makers determined information needs in relation to GEC for regional policy formulation, and gave rise to a number of possible research issues.

The eastern region of the IGP is a food deficit region characterised by low productivity, low inputs of fertilizer and water, risk of flooding, poor infrastructure and an out-migration of labour. Interdisciplinary research will be developed to address questions such as:

Theme 1: How will climate variability affect vulnerability to flooding within the region?

Theme 2: What are the market opportunities and management options for diversifying crops (e.g. aquaculture) to make more effective use of flood and groundwater?

Theme 3: How will these strategies effect labour migration, the interregional movement of food grains and water quality and river flow?

In contrast, the western region is a food surplus region characterised by higher investment, high productivity, major use of fertilisers and ground-water for irrigation, and an in-migration of labour. Interdisciplinary research will be developed to address questions such as:

Theme 1: How will climate variability affect change in water demand in high production regions of the IGP?

Theme 2: How can changes in water management (e.g. through policy instruments such as water pricing, and/or agronomic aspects such as alternative cropping, soil levelling) reduce vulnerability to climate variability?

Theme 3: What will be the consequences of changed water management on the local and regional socioeconomic situation; and on green-house gas emissions, water tables and land degradation?

A more detailed research planning exercise for the IGP is now being initiated with national policy makers and research groups; with international collaborators including the CGIAR, FAO and WMO; and with scientists IGBP, IHDP and WCRP. GECAFS will add value to the individual efforts of all its research partners by building on their complementary skills and contributions; it will not “replace” their existing efforts, but draw upon them, and set them in a broader canvas of societal concern.

Summary

Global environmental change is happening. Human activities, including those related to food, are now recognised to be partly responsible for changing the world’s climate and giving rise to other, globally- and locally-important environmental changes. These include alterations in supplies of freshwater, in the cycling of nitrogen, in biodiversity and in soils.

There is growing concern that the ability to provide food – particularly to more vulnerable sections of society – will be further complicated by global environmental change (GEC).
There is also concern that meeting the rising societal demand for food will lead to further environmental degradation, which will, in many cases, will result in further uncertainties for food provision systems.

Policies need to be formulated that enable societies to adapt to the added complication GEC will bring to food provision, while promoting socio-economic development and limiting further environmental degradation. Such policy formulation needs to be built upon an improved understanding of the links between GEC and food provision. The interdisciplinary project “Global Environmental Change and Food Systems” (GECAFS) is designed to meet this need.

Paper 2: The role of agronomic research in climate change and security policy

Adapted from:

<u>Ingram</u>, JSI, PJ Gregory and A-M Izac. 2008. The role of agronomic research in climate change and food security policy. *Agriculture, Ecosystems and Environment* **126**, 4-12.

Introduction

Human activities related to the production, supply and consumption of food, are partly responsible for changing the world's climate and giving rise to other, globally and locally important environmental changes. Such environmental changes include those in freshwater supplies, carbon and nitrogen cycling, biodiversity, and land cover and soils (Vitousek et al., 1997; Steffen et al., 2004). While climate change may bring benefits to some parts of the world, especially northern latitudes above about 55°, there is growing concern that overall these changes, and especially those associated with climate, will further complicate achieving food security for those in the developing world. This is due to the generally predicted deleterious impacts on agriculture, in particular in tropical and sub-tropical countries (Fischer et al., 2001; Rosegrant and Cline, 2003; Parry et al., 2004; Hadley Centre, 2006; Stern, 2006). There are three main reasons: first, many parts of the developing world are anticipated to be exposed to significant changes in temperature and rainfall patterns. Climate assessments for Southern Africa, for instance, conclude that the region will become warmer and drier (Hulme et al., 2001); a temperature increase of 2–5 °C is predicted over coming decades (IPCC, 2001) and increasingly variable rainfall is anticipated, with the region becoming generally drier, especially in the east (Scholes and Biggs, 2004). An increase in both frequency and intensity of extreme events (droughts and floods) is also anticipated (IPCC, 2001; Tyson et al., 2002b). Second, developing economies are particularly sensitive to the direct impacts of climate change given their often heavy dependence on agriculture and ecosystems, and because of their high poverty levels and geographic exposure (Stern, 2006). Third, many people in the developing world depend directly on agriculture as their primary source of food, and negative impacts on crop productivity will affect crop production and thereby overall food supply at the local level.

To compound the anticipated negative impacts of climate change on crop production, overall demands for food will increase as global population continues to rise from the ca. 6 billion people today to an anticipated ca. 9 billion by 2050 (UN, 2004). It is clear that overall crop production will need to continue to increase by 50% over the next few decades to meet this anticipated demand, although predicting future global food production is complex (Döös, 2002). This brings further concerns that, if the rising demand for food is met through current technologies and cropping practices, further environmental degradation is inevitable (Tilman et al., 2002; Bruinsma, 2003). An example is that the increased use of fertilisers would lead to higher greenhouse gas emissions which in turn exacerbate climate change ("climate forcing"). Such changes would in turn further undermine food production.

Agronomy therefore faces two major challenges. The first is to help develop food production systems that both improve food supply in the face of climate change, while simultaneously reducing factors responsible for climate forcing (Figure 1). The second is to work more effectively with a range of other disciplines to help deliver agronomic outputs both better integrated within the overall context of food security and better tuned to the needs of food security policy formulation.

Agronomic research on the impacts of climate change

Advances in crop breeding and agronomy have enabled increase in crop yields over the last 40 years or so. In Europe, for instance, yields have increased steadily and approximately linearly over the last 45 years (Figure 2), and in the USA, similarly, linear increases in maize, rice and wheat yields (61, 54 and 41 kg ha^1 $year^1$, respectively) have been recorded over the last 50 years (K. Cassman, *pers comm*).

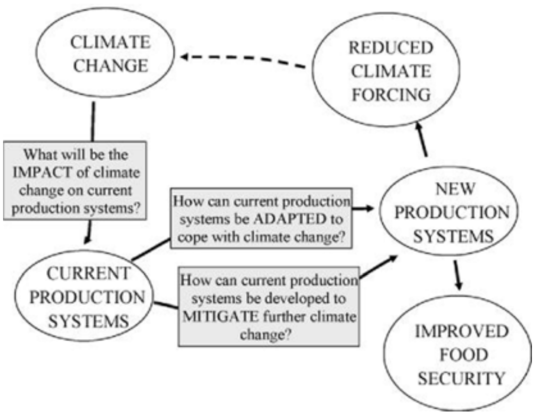

Figure 1 Overarching research questions relating to climate change impacts, adaptations and feedbacks.

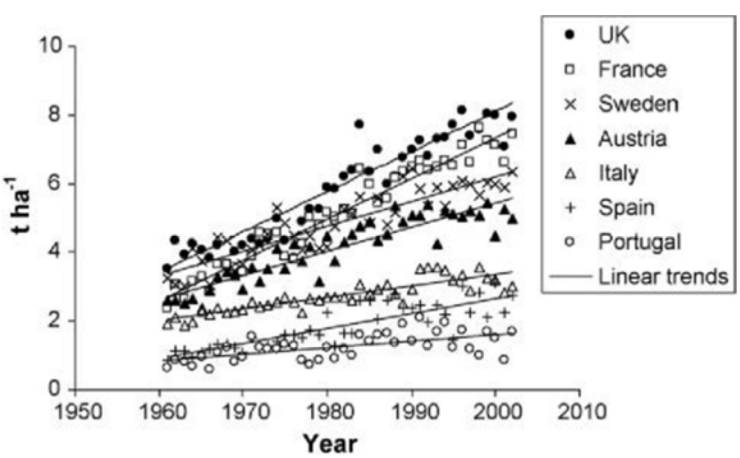

Figure 2 Observed wheat grain yields for selected countries in Europe (from Ewert et al., 2005).

These advances have resulted from a fortuitous combination of factors including scientific advances in irrigation practices, fertiliser formulation and application technologies, weed control including herbicides, disease and pathogen control using pesticides, and improvements in crop phenotype from breeding especially the widespread adoption of semi-dwarfing genes in cereals (Evans, 1998). Globally, these advances have increased average global cereal productivity (yield per unit area) from 1.2 Mg ha^{-1} in 1951 to about 3.4 Mg ha^{-1} currently with projected increases to 4.2 Mg ha^{-1} by 2020 (Dyson, 1996). This increased production per unit area, coupled with small increases in the area cropped, has compensated for the decrease in cropped area per caput (Figure 3).

However, while crop yields have increased throughout North America, Europe, Australia and Asia, this has not occurred in much of Africa. For example, Sanchez et al. (1997) show that per capita food production in Africa decreased by about 5–10% between 1980 and 1995, and FAO data analysed by Greenland et al. (1998) demonstrate significant decreases in crop yields in several African countries; the number of countries in Southern Africa classified as 'food surplus' has actually declined over the last decade (Drimie et al., 2011). The reasons for the comparatively poor performance of African agriculture are many and complex but include social instability, poor governance, weathered soils deficient in nutrients, and climatic variability making reliable irrigation problematic. Greenland et al. (1998) concluded that in many parts of Africa the yield decreases were a consequence of declining soil fertility—a process that could be reversed with inputs of fertilisers if money were available to purchase inputs. It is noteworthy that globally about 40% of crop production comes from the 25% of land that is irrigated. Restricted or irregular water supply is a major factor constraining crop productivity and this is evident in many data sets. Figure 2, for example, shows yields rising more slowly in the Mediterranean countries compared with those in northern Europe due to less favourable agroecological conditions related to less rainfall (but also higher temperatures leading to shortened growing period). Similarly, yields of wheat (grown mainly in rainfed conditions) in the USA (data given above) have increased more slowly than those of maize and rice which are often irrigated.

Figure 3 World cereal yield and area harvested per capita. Based on Dyson (1996) and updated from FAOSTAT-Agriculture (2006).

Given the past success in increasing crop productivity globally, why should we be worried by climate change? The answer is found in outputs from the last two decades or so of increasing research effort by crop scientists and agronomists worldwide on the impacts of climate change on the world's major crops. Much of this work has been reviewed and summarised by the IPCC in its Assessment Reports and by others (e.g. Fischer et al., 2001; Fuhrer, 2003; Rosegrant and Cline, 2003; Parry et al., 2004), and shows the largely negative impacts that increased temperature will have on crop productivity. The major emphasis of this research has been on the impacts on crop yield and there is clear crop physiological and agronomic evidence that climate change will significantly reduce productivity. For instance, Gregory et al. (1999) summarized experimental findings on wheat and rice that indicated decreased crop duration (and hence yield) of wheat as a consequence of warming and reductions in yields of rice of about 5% for each degree rise above 32 °C. These effects of temperature were considered sufficiently detrimental that they would largely offset any increase in yield as a consequence of increased atmospheric CO_2 concentration [CO_2]. Impacts on maize, another of the world's most important crops, has also received considerable attention (e.g. Jones and Thornton, 2003; Stige et al., 2006), suggesting reduced maize production if the global climate changes toward more El Niño-like conditions, as most climate models predict. This will have consequences for farm incomes: a recent pan-African study of climate change impact on African agriculture (Kurukulasuriya et al., 2006) concluded that net farm incomes of African farmers are highly vulnerable to climate with estimated elasticity of response to a unit degree increase in temperature ranging from -1.9 for dryland crops to -0.5 for irrigated crops. Other studies (e.g. Kettlewell et al., 1999; Slingo et al., 2005) have investigated the effects of climate variability on wheat protein content and other key aspects of crop quality.

Adaptation to climate change

The results on the impacts of climate change on crop productivity (which has been the main emphasis of climate change/food security research in recent years) indicate the first major role for crop scientists and agronomists: the need to contribute, with other scientists and farmers, to the development of new cropping systems which are resilient to changed climate conditions – and better still – more productive (Figure 1). This is because it is clear that climate change will affect productivity of current cultivars and cropping methods. This will in turn both complicate matters for those currently suffering food insecurity and also frustrate attempts to increase crop production in response to growing demand over coming decades.

Until recently most assessments of the impacts of climate change have been made assuming no modification to crop production practices. It is highly probable, though, that the changes of climate and [CO_2] will occur sufficiently slowly that changes to sowing date, cultivar, crop and other management practices will allow at least some adaptation of the production system by farmers. Several adaptations are conceivable in the timescale available including:

- Crop selection to determine mechanisms and sources of durable disease resistance.
- Crop selection to identify mechanisms and sources of resistance/resilience to abiotic stresses including heat, cold and drought.
- Genetic enhancement to cope with more variable growing conditions.
- Development of new crops to take advantage of more favourable growing conditions.
- Movement of some cropping systems from locations where climate has become unsuitable to locations that have become more favourable.

Indications of the benefits to be gained through adaptive responses are few at present, but simulation of production for cropping systems in northern and central Italy showed that the combined effects of increased [CO_2] and climate change would depress crop yields by 10–40% if current management practices were un-amended largely because of the warmer air temperatures accelerating the phenology of current cultivars (Tubiello et al., 2000). Through a combination of early planting of spring and summer crops and the use of slower-maturing winter cereal cultivars, though, the model indicated that it should be possible to maintain present yields. However, a major caveat to this conclusion was that 60–90% more irrigation water was required to maintain grain yields under conditions of climate change; this water was assumed to be available (Tubiello et al., 2000). This brings further concerns as climate change may lead to altered water regimes which, coupled with increased demands on water throughout temperate regions and tropical and sub-tropical regions, may lead to water scarcity (UNDP, 2006). More studies of this type are necessary to allow the most effective forms of adaptive strategy to be identified for specific cropping systems and specific regions, and to this end agronomists need to work more closely with hydrologists and water managers.

Climate change may also bring new pests, diseases and weeds. It is already clear that some pests will be able to invade new areas and become increasingly problematic for the maintenance of biodiversity, the functioning of ecosystems and the profitability of crop production. Some pests which are already present but only occur in small areas, or at low densities may be able to exploit the changing conditions by spreading more widely and reaching damaging population densities. Aphids for instance, key pests of agriculture, horticulture and forestry throughout the world, are expected to be particularly responsive to climate change because of their low developmental threshold temperature, short generation time and dispersal abilities (Sutherst et al., 2007). Again, agronomists will need to continue to work to help develop integrated pest management and other approaches to help combat the potentially enhanced losses to pest, diseases and weeds.

Agronomic research to reduce deleterious feedbacks to climate

The second major role for agronomy is in identifying methods to increase production without further exacerbating climate change (Figure 1). Options for increasing production to satisfy demand include either using new land (increasing area cropped: extensification) and/or increases in productivity (increasing yield per unit area: intensification). Globally, no one means will be adopted and different regions will increase production in different ways (Bruinsma, 2003).

Extensification will contribute to increases in production (total amount produced) but increases via this method are limited by the availability of new land, and the tradeoffs with greenhouse gas emissions and other deleterious environmental impacts (Gregory et al., 2002). About 3 billion ha of the world's land is suitable for arable agriculture and 1.2 to 1.5 billion ha of the most productive land is already cultivated (Greenland et al., 1998). Most of the potentially available land is presently under tropical forests so cultivation of more of this land is undesirable with respect to biodiversity conservation, greenhouse gas emissions and regional climate and hydrological changes. Cultivation for agriculture would also incur high costs to provide the necessary infrastructure. In general, then, further extensification of agriculture will likely provide only a small fraction of the increased production needed. Typically new areas of crop land will only contribute 7.4% (51 Mha) to cereal production on a global basis by 2020 with estimated contributions of extensification to crop production range from 47% in sub-Saharan Africa to 18% in South Asia (Alexandratos, 1995). It will be up to the governments of the countries concerned to decide whether tropical forest conversion is a policy option for their country.

Intensification will continue to be the main method for increasing food production. Gregory et al. (2002) identified three types of intensification, each of which has different environmental feedbacks. Type I intensification occurs when externalities and available management inputs are limited, and is still common in much of sub-Saharan Africa. Net environmental impacts are slight. Type II intensification is largely dominated technologically by the features of the "green revolution", and has been widely adopted from about 1960. It involves the introduction of new cultivars coupled with large increases in the use of fertilisers, herbicides, pesticides, irrigation and mechanisation. The adoption of this technology successfully achieved its primary aim of substantially increasing food production. At the same time, it also triggered very substantial negative environmental feedback processes. Hence, in the Indo-Gangetic Plain (IGP, one of the principal "green revolution" success story regions) the increased adoption of the rice–wheat system during the last three decades has resulted in the heavy use of irrigation, fertilizers, electricity and diesel (Aggarwal et al., 2004). These practices have had a direct impact on the emissions of greenhouse gases (especially CO_2, CH_4 and N_2O), as well as on a range of other environmental factors, and have also had some deleterious impacts on human health in the region. Depending on the management practices used, emissions are estimated collectively to have a global warming potential equivalent to 3000–8000 kg C ha^{1} year^{1} (Grace et al., 2003) which amounts to a significant quantity of carbon for the whole IGP. Type III intensification ("double green revolution") necessitates a production system that is both high yielding and environmentally benign. Affluent populations are pressing for this and demonstrated examples, rare only a few years ago in part due to the absence of comparative datasets (Gregory et al., 2002), are now beginning to emerge (e.g. Pretty, 2005).

Agronomic science is central to improving input-use efficiency in Type II and searching for viable options for Type III. This is especially important given the feedbacks to climate forcing discussed above, and is therefore high on the policy agenda. While increasing production in the future may further increase emissions if no changes in practice are wrought, alternative management strategies could effectively reduce emissions (Gregory et al., 2005). For example, surface seeding and/or zero-tillage, and the establishment of upland crops after rice gives similar yields to crops planted under normal conventional tillage over a diverse set of soil conditions, but reduces costs of production and allows earlier planting which offers higher yields. The practice also increases the efficiency of water and fertilizer use. It is worth noting, however, that while such increases will help meet demand, the yields required using current technologies are anticipated to fall short of those needed by 2020, let alone 2050 (Bruinsma, 2003).

Depending upon the international policy environment and opportunities (e.g. carbon markets, or payments for ecosystem services) extensification and intensification may take place with very different agricultural practices than those that dominate the landscape in tropical and subtropical countries today. This offers the potential for opportunities to overcome concerns about biogeophysical (e.g. changing albedo though changes in vegetation cover and dust) and biogeochemical (e.g. increasing greenhouse gas emissions) feedbacks to the climate system through climate forcing associated with current extensification and intensification (Gregory et al., 2002).

Agronomic research in relation to regional food production

As pointed out above, the major emphasis of climate change/food security research over recent years has been concerned with the impacts of climate change on crop yield. Further, such studies have often sought to limit yield-reducing factors related to pests, weeds and pollution (unless such factors were the subject of enquiry). While several key research issues remain (Figure 4, left-hand column), agronomic research has thus far provided an excellent foundation for assessments of how climate change may affect crop productivity. The connectivity between these results and the broader issues of food production at large scales are, however, relatively poorly explored.

Agronomic research has traditionally been conducted at plot scale over a growing season or perhaps a few years, but many of the issues related to regional production operate at larger spatial and temporal scales. Aware of the need for better links between agronomic research on crop productivity at plot scale and regional production, especially over time, the last decade or so has seen agronomists beginning to establish trials at landscape scale. There are, however, several considerable methodological challenges to be overcome at such scales (Figure 4, middle column). The first is to work more effectively with economists and other social scientists, as well as with system ecologists, to capture the key biophysical, social, economic and ecological processes at play at different spatial scales. This includes analysing interactions among variables from one scale to the other. For instance, a decrease in maize yield at the plot or field level may lead farmers to decide to shift to other crops (e.g. beans or cassava). If the shift is significant at the regional scale, changes in the price of maize versus that of the alternative crops will take place. These changes in relative crop prices will trigger further changes in farmers' practices and in their adaptation of their systems to the market. Agronomists will have to try and facilitate farmers' evolving practices, realising that these are not dictated uniquely by changing crop yields, but are also the consequence of factors which are sometimes extremely difficult to predict (e.g. the availability of germplasm for cash crops that hitherto had not been grown). At the same time, a significant shift in farming practices at the farm level, if also implemented by many farmers, can have ecological consequences at the watershed level. For instance, planting trees on contours to harvest fruit or other non-timber products to compensate for decreased crop yields could have a positive hydrological effect at the watershed scale. This will, in turn, open up new cropping opportunities for farmers. This process of adaptation of farming practices to shocks and stresses is on-going and very characteristic of farming communities the world over. Problems in understanding the motivations of farmers have occurred, however, because separate disciplines have tried (largely unsuccessfully) to provide explanations from the perspective of their own specific discipline. Further, researchers have often largely ignored the fact that farmers integrate multiple factors in their decision making, and are continually making decisions about trade-offs between outcomes of their management activities.

The analysis of trade-offs among different goals (e.g. increased profitability vs. conservation of biodiversity, or increased yields vs. increased water pollution, or trade-offs between economic, social and ecological and agronomic sustainability) is in its infancy and few methods are available. The third major role for agronomists is therefore to help develop the methodological breakthroughs needed in this respect. These are needed to help the design of agricultural systems that are more responsive to both societal needs (e.g. adaptation to climate change, environmental preservation, regional and national food security, poverty and hunger alleviation) and to the needs of farmers (e.g. moving out of poverty, human dignity).

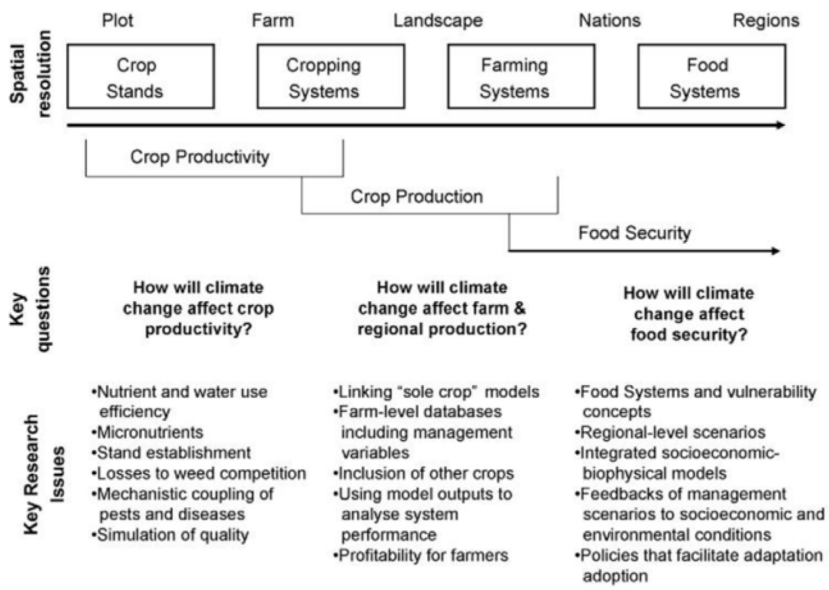

Figure 4 Relationship between spatial resolution, key research questions and issues.

Agronomic research in relation to food security policy

Food security is the state when '*all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life*' (FAO, 1996a). So, while production is clearly a critical element contributing to food security, other factors dealing with access to food and food utilisation are also important (Ericksen, 2008a); too often discussions on food security policy appear to be based on a relatively narrow agronomic perspective because the links between climate change and the broader issues related to food security have, to date, been relatively unexplored (Gregory et al., 2005). There is therefore a fourth important role for agronomy, namely to couple research on impacts and adaptation more effectively to food security policy, particularly given the increasing prominence of the agriculture/biofuels debate. To overcome the limitation of current agronomic research outputs in this arena there are several scientific challenges where further agronomic effort is necessary. As food security is underpinned by an effective food system, setting food production research within the context of food systems provides a promising way forward. 'Food systems' are a set of dynamic interactions between and within the biogeophysical and human environments. They include a number of activities (producing food; processing, packaging and distributing food; and retailing and consuming food) which lead to a number of associated outcomes some which contribute to food security (i.e. food availability, access to food and food utilisation), and others which relate to environmental and other social welfare concerns (Ericksen, 2008a). While agronomic research clearly has a leading role in activities relating to producing food, there is also a need to consider agronomic input to other aspects of the food system. Examples include food quality (in relation to, e.g. storage and processing characteristics), timing of production (in relation to, e.g. market opportunities) and diversity (in relation to, e.g. nutritional balance). As food security is diminished when food systems are disrupted or stressed, food security policy needs to address the whole food system. To this end, agronomic research needs to be better linked to wide-ranging interdisciplinary studies (e.g. vulnerability of food systems; Figure 4, right hand column) and across sectors of the food industry. This will facilitate the building of integrated socioeconomic-biophysical models that will enable analysis of adaptation options to food systems, thereby underpinning policy formulation for improved food security.

This raises another major challenge, namely understanding how best to address the information needs of policy makers and report and communicate agronomic research results in a manner that will assist the development of food systems adapted to climate change. To be of use in supporting policy formulation, research on the development and assessment of possible strategies to adapt food systems to the impacts of climate change should be elaborated in the context of the policy process. As the food security–climate change debate encompasses many complex and interactive issues, a structured dialogue is needed to assist the collaboration among scientists and policymakers.

Table 1 Necessary reconsiderations in research viewpoints so as to increase the effectiveness of the contribution of agronomic research to food security issues (from Maxwell and Slater, 2003)

Viewpoints under the traditional agenda	**Viewpoints under the new agenda**
Policies, institutions and investments in agriculture	Policies, institutions and investments in and for agriculture
One rural world	Multiple rural worlds
National markets	National, regional and global markets
Production units	Livelihood units
Agriculture = production agriculture	Agricultural sector = (inputs + production + post-harvest + manufacturing + ecosystem services
Single sector approach	Multi-sector approaches
Public sector	Public and private sectors
Food crops	Diverse income streams
Growth only	Growth that minimises risk and vulnerability, with equity in distribution of benefits and resilience (through integrity of ecosystem services)
Driven by supply (and technological breakthroughs)	Driven by societal demand
Fundamentals acknowledged (the fundamentals are science, technology, infrastructure, land policy, and education, extension and training)	Fundamentals delivered (the fundamentals are science, technology, infrastructure, land policy, and education, extension and training)

This can be facilitated using a variety of decision support (DS) approaches and tools, ranging from general discussions and mutual awareness-raising (including formal joint exercises such as scenarios construction and analyses) to simulation modelling, GIS and other tools for conducting quantitative analyses of trade-offs of given policy options. Application of this holistic DS process (i) raises awareness in the policy community of the interactions between climate change and food production (and other aspects of the food system), (ii) identifies and communicates the options and constraints facing researchers and policymakers, (iii) identifies methods and tools that best facilitate the dialogue between scientists and policy makers related to climate change and food systems and (iv) helps both researchers and policymakers assess the viability of different technical and policy adaptation strategies by analysing their potential consequences (feed backs) for food security and environmental goals.

The discussion above identifies a number of research challenges facing the agronomic research community. The final point relates to the overall viewpoints from which researchers, resource managers and policy makers operate. These viewpoints need to be reconsidered for the innovative agronomic research approaches to address food security concerns in the face of climate change to have maximum effectiveness (Table 1). Such reconsiderations will both heighten the relevance of agronomic research to the broader food security issues and help deliver more policy-relevant outputs. They are, of course, needed not just on the part of agronomists, but on the part of all the other sciences and disciplines that are relevant to agricultural research for development.

Conclusions

While agronomic research alone cannot solve all food security/climate change issues (and hence the balance of investment in research and development for crop production vis a vis other aspects of food security needs to be assessed), it will nevertheless continue to have an important role to play: it both improves understanding of the impacts of climate change on crop production and helps to develop adaptation options; and also – and crucially – it improves understanding of the consequences of different adaptation options on further climate forcing. This role can further be strengthened if agronomists work alongside other agricultural scientists to develop adaptation options that are not only effective in terms of crop production, but are also environmentally and economically robust, at landscape and regional scales. Agronomists also need to work with a wide range of other disciplines, and across sectors of the food industry, to develop the necessary new research approaches and paradigms to better link research on food production to food security issues. Such novel approaches more likely to deliver scientific outputs better suited to the information needs of policy makers.

Paper 3: A Food Systems Approach to Researching Food Security and its Interactions with Global Environmental Change

Adapted from:

Ingram, JSI. A Food Systems Approach to Researching Food Security and its Interactions with Global Environmental Change. Re-submitted with revisions to *Food Security*, 3 June 2011.

Food security – a re-emerged topic

> "*The world now produces enough food to feed its population. The problem is not simply technical. It is a political and social problem. It is a problem of access to food supplies, of distribution, and of entitlement. Above all it is a problem of political will.*" Boutros Boutros-Ghali, Conference on Overcoming Global Hunger, Washington DC, 30 November 1993 (quoted in Shaw, 2007).

Food security (or more correctly, food insecurity) has long been associated with 'developing world' issues. From the perspective of the industrialised world, it has hence been the purview of development agencies (e.g. AusAID, 2004; U.S. Government, 2010), rather than government departments and other national agencies concerned with domestic agendas. In the UK, for instance, few – if any – government documents since the Second World War about conditions *within* the UK included 'food security' in the title. Recently, however, and largely driven by the food price 'spike' in 2007-08, the notion of food security has rapidly ascended policy, societal and science agendas in countries worldwide, and has been the topic of special issues of leading scientific journals e.g. *Philosophical Transactions of the Royal Society B* (Godfray et al., 2010a) and *Science* (Science, 2010), government reports (e.g. Defra, 2006; EU, 2011; Foresight, 2011) and leading high-circulation media such as the *Economist* (21 November 2009; 24 February 2011). While most attention is directed towards the plight of many in the developing world, it is important to note that food insecurity occurs in all countries to some extent: in the US, for instance, the problem affects nearly 13 million households annually (Wisconsin WIC Program, 2007).

Much of the food security debate understandably centres on aspects of food production and this has long been the subject of major research investment. Increasing production has always been an important strategy to help alleviate food insecurity, and it still is today. There is hence still a strong sentiment that producing more food will satisfy society's needs, and theoretically this is of course the case: produce enough and all will be fed. However, despite the fact that more than enough food is currently produced *per capita* to adequately feed the global population, about 925 million people remained food insecure in 2010 (FAO, 2010). For many, this gap in production vs. need is more related to the political economy of interventions and political inertia in funding decisions than to technical ignorance (see quotation above). Given that food prices are again high – in March 2011, the food index remained 36% above its level a year earlier (World Bank, 2011) – there is a strong likelihood that this number will again rise.

This link between food prices and numbers of food-insecure people underscores the importance of the affordability of food in relation to food security. This is reflected in the commonly-used definition stemming from the 1996 World Food Summit (FAO, 1996b) which states that food security is met when "*all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life*". This definition puts the notion of access to food centre stage. Further, not only does it bring in a wide range of issues related to a fuller understanding of food security, but some key words such as "food production" and "agriculture" – which might have been expected in such a definition – are *not* included; the emphasis changed from increasing food production to increasing *access* to food for all. This definition also integrates notions of food availability and food utilisation. Many other definitions of food security exist; even by 1992 Maxwell and Smith had counted over 200 (Spring, 2009) and more are still being formulated (Defra, 2006). The majority of the more recent (i.e. since the 1990's) definitions have the notion of access to food central and are now manifestly very valuable in raising the profile of access to food in relation to producing food.

While it is important to note that an inability to access food is the main cause of food insecurity in general, some parts of the world, and especially in sub-Saharan Africa, still face chronic hunger due to low food production. This can be due to low fertility soils, and/or lack of sufficient land. Many such areas are also anticipated to be most severely affected by global environmental change (GEC), and especially climate change (Parry et al., 2005; Lobell et al., 2008). Nevertheless, this shift over recent decades towards a more integrated food security concept challenges the research community to think more broadly than food production alone. It raises questions ranging from overarching issues related from frameworks for conceptualising food security and identifying GEC-related and other key limiting factors which determine it, to more detailed issues related to specific research foci to overcome them. This paper lays out a case for a food systems framework to help address the overarching issues and identify the limiting factors and how they interact. It also provides a number of examples of how selected elements of the framework can help define varied aspects of food security research to address these limiting factors.

Food security research approaches

In addition to highlighting the importance of access to food, the more holistic concept that recent definitions of food security embody identify a wide range of research challenges spanning the humanities and social and economic sciences, rather than just biophysical sciences (Pálsson et al., 2011). There is however still a predominant research emphasis on increasing crop productivity, i.e. yield (biomass/unit area); a search on Google Scholar on 1st June 2011 for articles published between 2005 and 2011 with the words "crop yield" or "access to food" / "food access" in the title identified 1360 and 230 references, respectively. Given the need to produce more food this is of course very important, but it is also driven by the momentum of research in this area. As most of our food comes from crops, research has historically concentrated on agronomy (usually focussed on the experimental plot or field level, and usually for a single cropping season) and its associated sciences, although livestock and fisheries also received considerable attention. This research has been vitally important and has delivered a wide array of technological productivity advances; average yields of the world's main grains (wheat, barley, maize, rice and oats) have increased three-fold since 1960, although increases for coarse grains (millet, sorghum) and root crops (cassava and potato) have been nearer level (FAO, 2009b). When adopted over a large area these technological advances have led to greatly enhanced production.

These advances have not been without significant environmental cost, and there is now a strong drive to reduce negative externalities such as soil degradation, water pollution, loss of biodiversity and greenhouse gas emissions. Nonetheless, and driven by recently increasing concerns about population growth and rising incomes leading to changing diets, the main motive for most agricultural research remains the need to yet further increase food production. However, and as pointed out above, the fact that so many people are still facing food insecurity despite global production currently being sufficient for all, indicates that research which considers multiple aspects of food security and food systems is needed. How can the research 'powerhouse' be better geared towards the needs of the upcoming decades, especially given anticipated changes in climate and other environmental and socioeconomic factors?

Agronomic research is undoubtedly still vitally important, and the author and colleagues outlined three major challenges for agronomists in the climate/food security debate: (i) to understand better how climate change will affect cropping systems (i.e. the arrangement in which various crops are grown together in the same field, as opposed to crop productivity); (ii) to assess technical and policy options for reducing the deleterious impacts of climate change on cropping systems while minimizing further environmental degradation; and (iii) to understand how best to address the information needs of policy-makers and report and communicate agronomic research results in a manner that will assist the development of food systems adapted to climate change (Ingram et al., 2008). In addition, to contributing more effectively to the food security/environmental change debate, the agricultural research community should more actively consider how to translate findings at plot-level over a few seasons to larger spatial and temporal levels and thence to the issues of food security. Methods for estimating *regional* production – and especially how it will change in future – are still relatively weak, with analyses mainly relying on statistical approaches or extrapolation from mechanistic point models, although mechanistic modelling approaches also exist (e.g. Parry et al., 2005; Challinor et al., 2007).

While research on producing food has allowed remarkable gains to be made, the dominance of this research community has overshadowed many other important aspects of research related to the full food system. However, while production increase continues to be an important goal, other activities such as processing food, packaging and distributing food, and retailing and consuming food are now all receiving increased attention, and the whole food chain concept ("farm-to-fork" or "plough-to-plate") is now well established (Maxwell and Slater, 2003; ESF, 2009). This concept not only helps to identify the full range of activities involved in the food system, but also helps to identify the actors involved, the roles they play, and the many and complex interactions amongst them (Ericksen et al., 2009).

A different approach to the food chain concept for food security research focuses on the substance of the definition from the 1996 World Food Summit, *vis*. food availability, food access, food utilisation and their stability over time (FAO, 1996b; Stamoulis and Zezza, 2003). These components are clearly different from the activities of producing, processing, distributing, etc. which characterise the food chain literature; rather than focussing on the "what we do" (i.e. the activities), they emphasise the "what we get" (i.e. the *outcomes* of these activities which collectively underpin food security).

While individual actors in the food system are of course primarily interested in their specific activity (i.e., food producing, processing, distributing, etc.) people not involved in these activities are essentially only interested in the food security outcomes of the activities (rather than in the activities *per se*). Research, however, needs to recognise that the technologies and policies that influence the manner in which all the activities are implemented directly affects the overall food security outcomes. This important point is discussed further below in Example 2: "Analysing the consequences of interventions on food security outcomes".

The 'food system' concept and its development for GEC research

In the late 1990s, as research interest within the international GEC research community grew on the interactions between GEC and food security, it became increasingly clear that the complexity of the issues involved needed a new approach; focus needed to move beyond the impacts of climate change on crop productivity (which had largely dominated GEC-food research to date). An innovative research agenda needed to clarify and frame (i) how GEC affects food security, (ii) how to adapt to the addition stress GEC brings, and (iii) how to implement our efforts so as to minimise further drivers of GEC. Based on a better understanding of what constitutes food security, members of the GEC research community charged with developing the new agenda agreed that research should be based on 'food systems' (Gregory and Ingram, 2000; Ingram and Brklacich, 2002).

The food system concept was not new: driven by social and political concerns, rural sociologists had promoted this approach for some years (e.g. McMichael, 1994; Tovey, 1997). Several authors have since put forward frameworks for analysing food systems, but

Sobal et al. (1998) noted that few existing models broadly described the system and most focused on one disciplinary perspective or one segment of the system. They identified four major types of models: food chains, food cycles, food webs and food contexts, and developed a more integrated approach including nutrition. Dixon et al. (1999) meanwhile proposed a cultural economy model for understanding power in commodity systems, while Fraser et al. (2005) proposed a framework to assess the vulnerability of food systems to future shocks based on landscape ecology's 'Panarchy Framework'.

Despite these varied approaches, none was suitable for drawing attention to, let alone analysing, the two-way interactions between the range of food systems activities and food security outcomes, and the full range of GEC of parameters. This was needed as adaptation to climate change and/or to other environmental and socioeconomic stresses, means 'doing things differently'. In relation to food systems, the 'things' that need to be done differently are the activities, i.e. the aspects that can be adapted are the methods of producing, processing, distributing food, etc., and adaptation options in all these need to be considered.

A new approach was needed for GEC research and for GEC community this was a clear departure from the food-related research which had hitherto concentrated on agroecology (Gregory et al., 1999). The food system approach thus characterised a new, interdisciplinary food security research project (Global Environmental Change and Food Systems, GECAFS) within the international GEC Programmes (GECAFS, 2005; Ingram et al., 2007b). Drawing on the extensive (yet relatively distinct) literatures built up by the food chain and food security communities, respectively, a key paper by Polly Ericksen (Ericksen, 2008a) formalised the 'GECAFS food systems' concept (Figure 1; Box 1).

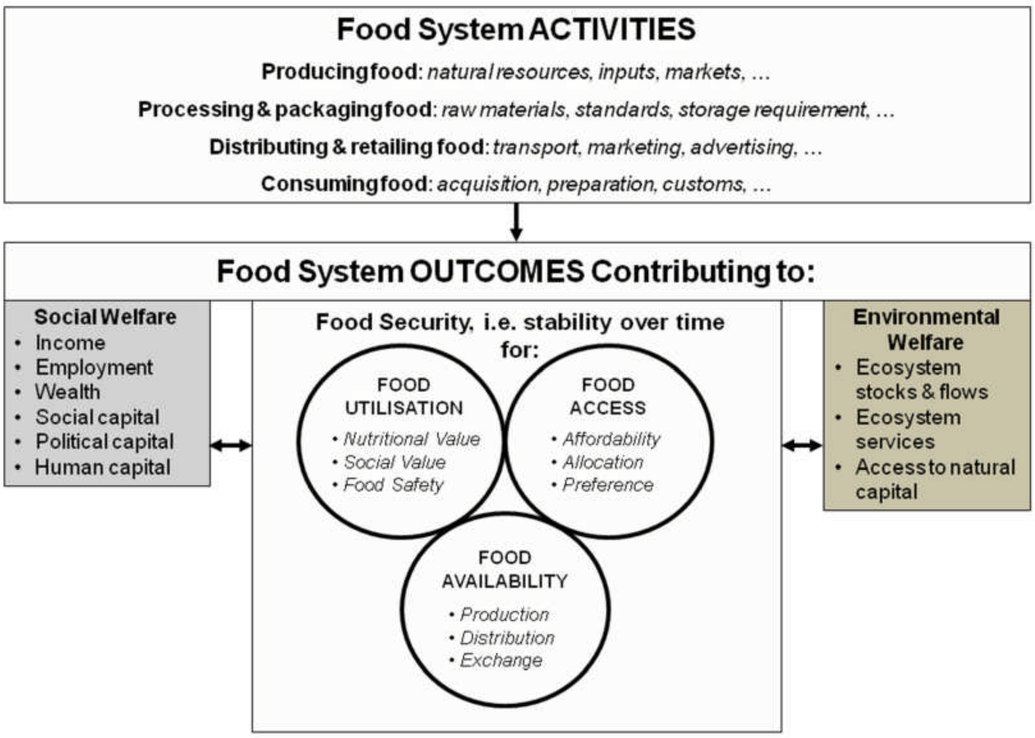

Figure 1 Food system *Activities* and *Outcomes* (adapted from www.gecafs.org)

Box 1 Food system *Activities* and food security *Outcomes* (Ericksen, 2008a; Ingram, 2009; Ericksen et al., 2010a)

Food systems encompass a number of *Activities* which give rise to a number of food security *Outcomes.*

Food systems *Activities* include: (i) producing food; (ii) processing food; (iii) packaging and distributing food; and (iv) retailing and consuming food. All these activities are determined by a number of factors ('determinants'). The determinants of 'packaging and distributing' food, for instance, include the desired appearance of the final product and other demands of the retailer, the shelf life needed, cold chain and/or other transportation infrastructure, road, rail and shipping infrastructure, trade regulations, storage facilities, etc. (Figure 1).

Undertaking these activities leads to a number of *Outcomes*, which not only contribute to food security, but also relate to environmental and other social welfare issues (Figure 1).

Food security outcomes are grouped into three components (Availability, Access and Utilisation), each of which comprises three elements (Figure 1). All nine elements have are either explicit or implicit in the FAO definition above (FAO, 1996b); all have to be satisfied and stable over time for food security to be met.

Both the activities and their outcomes are influenced by the interacting GEC and socioeconomic 'drivers'; and the environmental, food security and other social outcomes of the activities feedback to the drivers (Figure 2).

While enhancing food security may often be the prime motive when planning adaptation strategies for the additional stresses GEC is bringing, Figure 1 shows that the food system activities also give rise to other outcomes. These relate to other socioeconomic issues and conditions, and to the environment, and all have feedbacks to the food system drivers (Figure 2); while many factors not directly related to the food system (e.g. fossil fuel use generally, urbanisation) drive GEC, land-use change, intensified agricultural practices, overexploitation of fisheries, food processing and transport, etc. are all major drivers of GEC (see Example 4, below). What might be 'good' adaptation for food security might also be good for other socioeconomic and/or environmental outcomes – but it might also be worse; synergies and trade-offs need to be carefully considered, although the complexity of the food system makes analyses difficult. However, the current evidence of food insecurity and environmental degradation suggests that mal-adaptation may already be occurring (Ericksen et al., 2010b). The key questions are (i) which activity(s) should we best seek to adapt to improve food security for given situations; (ii) what will be the consequences of such adaptation strategies for the full set of food security elements; and (iii) what will be the synergies and trade-offs among the three food system outcomes and the feedbacks to food system drivers? Being highly aggregated the food system framework (Figure 2) cannot answer these questions *per se*, but it is useful for generating hypotheses that can be further explored using other more specific methods.

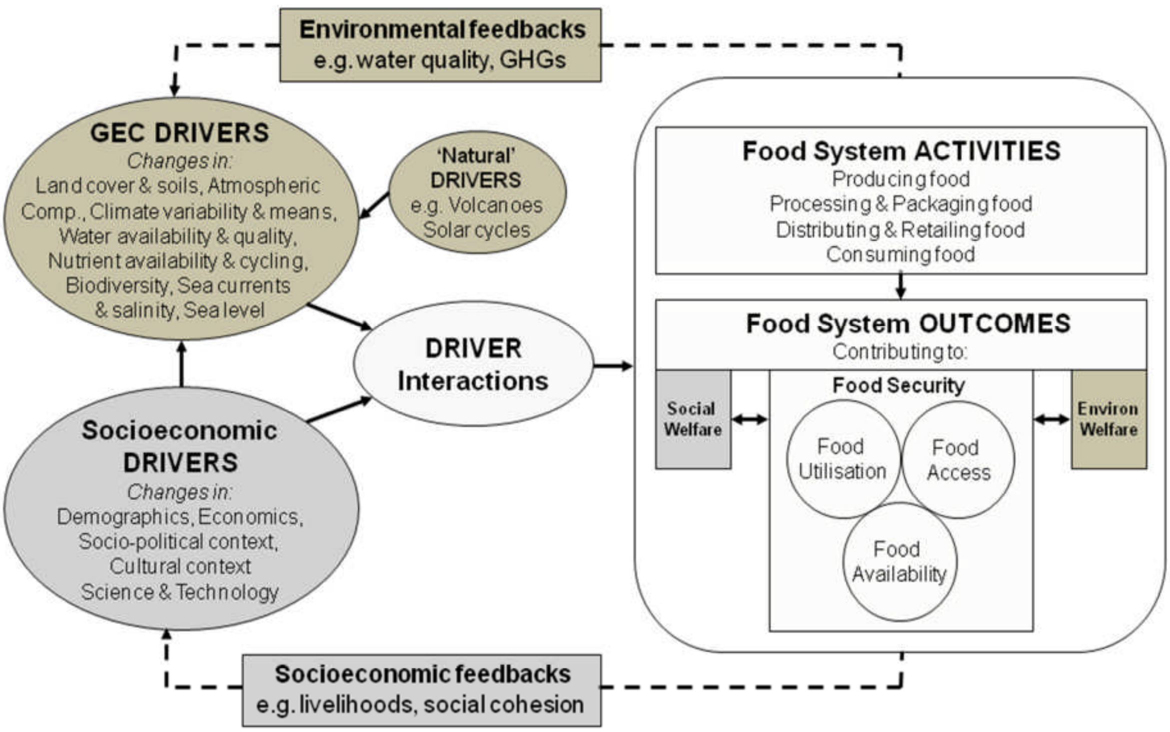

Figure 2 Food system drivers and feedbacks (adapted from www.gecafs.org)

The GECAFS food systems approach was specifically designed to help GEC research, and analyses of the impacts of changed biophysical environmental 'drivers' on food production are increasingly important, especially now that evidence has emerged of reduced yields worldwide due to climate change (Lobell et al., 2011). The approach however also notes that while a wide range of socioeconomic 'drivers' also need to be included in food security analyses, it is the interactive impact of these two sets of drivers that affects how the food system operates and hence how the food security and other outcomes manifest (Figure 2). Both the GEC and socioeconomic drivers can be (and usually are) a combination of local and non-local in origin. Global-level forces such as climate change, trade agreements, and world price for energy and food will affect local and regional food systems; land rights, local market policy, natural resource degradation and other local factors will affect the resilience of local food systems to these external, and also internal, stresses.

The food systems approach not only helps to engender discussion of adaptation options across the full set of food system activities (i.e. along the length of the food chain) rather than just, say, in the agricultural domain, but also provides a framework for systematic analysis of synergies and trade-offs, balanced across a range of societal goals. Further, it serves as a 'checklist' to ensure the range of outcomes (some hitherto unforeseen) is being considered by those planning and/or implementing adaption.

In addition to broadening the debate from the relatively-narrow, biophysical research on impacts of climate change on crop growth, the GECAFS food system concept was specially designed to enhance interdisciplinary research on the two-way interactions between GEC and efforts to meet food security. Integrating the notions of food system activities with food security outcomes (Figure 1), the GECAFS food system concept provides a framework for designing research to systematically analyse a wide range of GEC-food security interactions and questions. It has proven robust across a range of socioeconomic and geographical contexts, strengthened by the recognition of the range of 'scales' and 'levels' inherent in modern food systems. 'Scale' is the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon, and 'levels' is the units of analysis that are located at different positions on a scale (Gibson et al., 2000; Cash et al., 2006). A predominant feature of 21st Century food systems is that they are inherently cross-level and cross-scale (Ericksen et al., 2010a).

The following examples illustrate the utility of this food system concept for improving understanding of vulnerability of food systems to GEC; analysing the consequences of technical interventions on food security outcomes; analysing the consequences of food system activities for environmental parameters; framing scenario analyses; and analysing the food security dimension in international environmental assessments.

Example 1: Analysing the vulnerability of food systems to GEC and identifying adaptation options

There is a rich and diverse food security literature addressing the vulnerability of individuals and/or households to a range of stresses including GEC (e.g. (Adger, 2006; Ericksen, 2008b; Misselhorn et al., 2010)). By considering the whole food system, it is possible to identify where vulnerability arises within the full range of food system activity 'determinants', i.e. the factors that determine how a given food system activity in undertaken/operates (Eakin, 2010). Focussing on these, rather than the food security outcomes *per se*, helps indicate what, where and how adaptation measures to enhance food security in the face of GEC might be most effective. Further, looking across all food system activities offers the chance of identifying intervention points that might not be apparent if, for instance, one only considers the agricultural aspect. This is exemplified by a case study of the vulnerability of district-level food systems to GEC in the Indo-Gangetic Plain.

Major investment in infrastructure has allowed Ludhiana District of the Indian Punjab to developed very effective irrigated agriculture, but excessive ground water extraction (a locally-significant environmental change) has significantly lowered water tables, thereby reducing irrigation supply. This will be exacerbated by anticipated changes in rain and glacier melt, leading to a major vulnerability point relating to producing food. This, in turn threatens the 'producing food' activity, affecting the overall food production at the District-level and hence the 'availability' component of food security (Figure 1). In contrast, in the Ruhani

Basin District in Nepal's Terai region, where food production has historically often suffered from poor harvests, local food security depends on the ability to move food from village to village, especially in times of stress. Food distribution infrastructure is however not robust, and increased flooding due GEC-induced potential glacier melt coupled with more extreme weather will disrupt footpaths, bridges and other vital aspects, affecting the 'distributing' activity, and thence the distribution element of food availability (Figure 1). The food system approach identified the principle vulnerability points in the two Districts and shows them to be quite different. They will need very different adaptation responses to reduce their respective vulnerabilities. Improved water governance would reduce the food system vulnerability in the Indian case (Aggarwal et al., 2004), while in the Nepali case, investment in infrastructure and policies for strategic food reserves at local level are needed (Dixit, 2003).

Adaptation options to reduce food system vulnerability tend to focus on technical interventions to increase food production. By and large, and as noted above, these are targeted at increasing yields of crops, livestock or fish, and are important in many parts of the world, especially sub-Saharan Africa. These are complemented by advances in food storage, processing and packaging which have helped limit post-harvest losses and combat food waste. However, and as the Indian and Nepali cases show, options to adapt to the additional stresses that GEC will bring also need to be vigorously explored in the policy domain. These may be particularly effective when considered at regional level and over multiple years (Liverman and Ingram, 2010). Examples include establishing strategic grain reserves for a region, harmonizing regional trade and quarantine agreements, introducing water pricing and agreeing the sharing of water and other natural resources (Aggarwal et al., 2004), (Drimie et al., 2011). Other options related to improving regional infrastructure, such as road, rail and harbour facilities allow the rapid movement of food in a crisis. These all need to be considered when seeking ways to reduce the vulnerability of the food system to GEC, and the GECAFS framework helps to remind researchers and decision-makers of the wide range of potentials interventions that need to be considered.

Example 2: Analysing the consequences of interventions on food security outcomes

Example 1 discusses the identification of food system 'vulnerability points' and considers adaptation interventions in different food system activities (producing food and distributing food). When discussing adaptation interventions in response to GEC, it is important to explicitly state how a given intervention to a food system activity will affect the 'target' food security element. While adapting agronomic practise can have direct and clear impact on increasing food production, the impacts of more novel technologies on other food security outcomes may be less obvious, especially when applied to other food system activities. These include information and telecommunications (ITC) technologies which are playing ever-increasing roles in food systems. Although perhaps less relevant to developing world situations (at least at present) will likely constitute important tools in the basket of adaptation options. Examples already seen range from GIS technologies for fertilizer applications (Assimakopoulos et al., 2003) and laser technologies for field levelling (Jat et al., 2006) to radio-frequency identification (RFID) for traceability of produce though the food chain (Kelepouris et al., 2007) and low-cost detection of allergens in food stuffs (Bettazzi et al., 2008).

ICT technologies (as with all technologies) are applied to the food system activities, affecting the ways in which food producing, processing etc. are conducted. How will the application of ITC technologies affect the food security outcomes?

An initial analysis to address this question was conducted at a COST (European Cooperation in Science and Technology) workshop held in Bruges, Belgium in June, 2009. The GECAFS food system framework of four groups of food systems activities and nine elements of food security outcomes (Figure 1) was used to systematically identify examples of (i) how the application of example ICT technologies could be implemented in different food system activities, and (ii) how these could affect a range of food security outcomes. A number of the examples are presented in a matrix of activities vs. outcomes (Table 1).

<Table 1 placed at end of paper>

By clearly identifying the full set of food system activities and example elements of the food security outcomes (Figure 1), the GECAFS food system approach provided the structure for a matrix (Table 1) to systematically identify possible impacts of example ITC technologies on food security outcome. It details the way a given ICT technology can be applied to a given food system activity and how this in turn affects specific food security elements.

Example 3: Food system concepts for framing scenarios analyses

Scenarios are "plausible and often simplified descriptions of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces and relationships" (MA, 2005b). Scenarios are neither forecasts of future events, nor predictions of what might or will happen in the future. Rather, they develop and present carefully structured stories about future states of the world that represent alternative plausible conditions under different assumptions.

Scenario exercises are increasingly being used to help decision makers and other stakeholders address the 'big picture', complex challenges given future uncertainty. While the future of food production poses substantial questions (and hence is the focus of considerable research effort, as discussed above), the future of food security is even more complex. This is due to two main factors. First, the individual nature of the food system drivers (demand, trade arrangements, climate, etc.; Figure 2) is uncertain, let alone the critically-important interactions among them. Second, food security is itself complex: it has nine major elements all of which need to be satisfied (Figure 1), and all of which will vary depending on the future interactions of the drivers with the food system.

The nine food security elements (Figure 1) (as opposed to just production) were all included in a prototype scenario study in the Caribbean (GECAFS, 2006b). This region is highly dependent on external food sources, exposed to extreme weather events and is in the process of implementing a new regional trade system (CARICOM Single Market and Economy, CSME). Further, as elsewhere, there are considerable uncertainties associated with all the food system drivers (Figure 2) so the scenarios approach was advocated. The key interest to regional policy makers, researchers and resource managers was how a range of different plausible futures would affect the food security of the region.

The scenarios exercise involved four main steps: (i) Key regional GEC and policy issues were identified through stakeholder consultation workshops involving regional scientists and policymakers; (ii) a set of four prototype regional scenarios were drafted based on the broad rationale, assumptions and outcomes of the MA scenarios exercise (MA, 2005b), but allowing for regional deviation where needed; (iii) developments to 2030 per scenario for key each food security determinant (Figure 3; and see GECAFS (2006b) for full details of the method). It must be noted that scenarios are not predictions but analyses of how plausible futures may unfold.

The use of the GECAFS food system approach can also be found in the scenarios exercises for the CGIAR's new Consortium Research Project 7 "Climate Change, Agriculture and Food Security" (CCAFS). Here the objective is to identify viable technical and policy interventions to adapt agriculture and food systems to climate change so as to improve outcomes for food security, livelihoods and environmental benefits (CCAFS, 2009). Scenarios exercises are being conducted in each of the three initial research regions (East Africa, West Africa and the Indo-Gangetic Plain). In order for potential synergies and trade-offs between these three outcomes to be assessed a small number of elements (variables) for each of these three outcomes had to be agreed. Using the food system approach as a framework, regional stakeholders identified four critically-important elements for the region's food security, for environmental factors, and for livelihoods. Food security elements included (i) the affordability of staple foods; (ii) the regional production of staple foods; (iii) the effectiveness of distribution mechanisms; and (iv) the nutritional value of staple foods (CCAFS Scenarios Team, 2010).

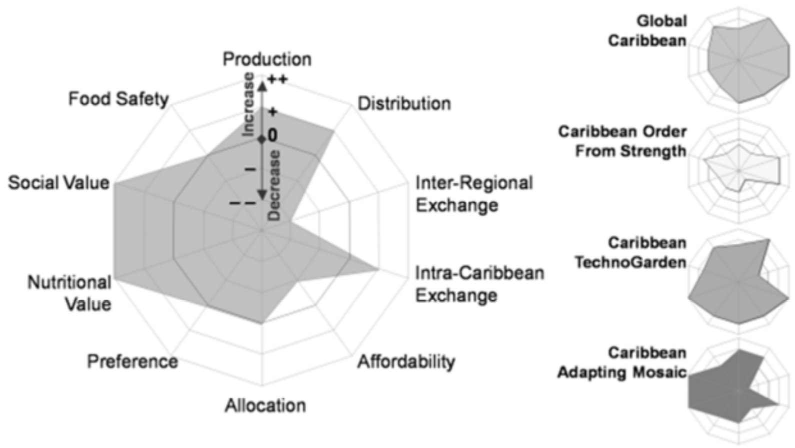

Figure 3 Outcomes for 10 variables that collectively determine food security for four plausible futures for Caribbean food systems (reproduced from (Ingram and Izac, 2010), with permission). A rating of (++) indicates a high increase (i.e. outermost ring in the chart) and a rating of (+) to some increase (i.e. the second outermost ring in the chart). Conversely, a rating of (--) implies high decrease (i.e. the innermost ring of the chart) and a rating of (-) reads as some decrease (i.e. the second innermost ring of the chart). Finally, a rating of (o) translates to no changes versus the current situation and a rating of (+/-) shows mixed trends with some increase in some aspects alongside decreases in others (i.e. both are depicted by a value on the 'dashed line' centre ring) (GECAFS, 2006b).

This CCAFS example highlights an important point about the framework: it serves as base that can be further developed to be more useful and specific in a dynamic context, which can lead to a number of valuable research avenues. The framework is qualitative and more quantified analyses will be needed for many discussion-making processes. For instance, a range of models aimed at quantifying (as far as possible) the four food security elements is being identified by the CCAFS group with a view to 'driving' the axes of the spidergrams exemplified in Figure 3 (CCAFS Scenarios Team, 2010). The aim is to model how each variable (axis) evolves over time for each scenario, noting changes both within and between different scenarios, with a view to including the impact of technical and/or policy interventions over time.

These scenario exercises deliver a number of related outputs related to Figure 3: (i) an analysis of all elements of food system outcomes (multiple axes on graphs); (ii) an assessment of how each outcome determinant would change (change of position along axes);

(iii) the ability for a policy interpretation of different future conditions (comparing graphs); and (iv) adaptation insights at the regional level for improving overall food security (where to concentrate effort on enlarging the polygon areas of each graph). It also brought together a wide range of specialists and representatives of the many stakeholders involved in food systems who hitherto had not interacted. It should be noted, however, that purpose of these initial scenario exercises was to investigate food security outcomes of plausible futures. They were not designed to determine adaptation pathways, which should form the subject of follow up research.

Example 4: Quantifying the contribution of food system activities to crossing 'planetary boundaries'

Many human activities affect environmental conditions, degradation of which will undermine the natural resource base upon which food systems are founded. This example discusses how food system activities affects environment (the 'feedback'; Figure 2), and is based on the notion of 'planetary boundaries'. These define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes. If these thresholds are crossed, then important subsystems, such as a monsoon system, could shift into a new state, often with deleterious or potentially even disastrous consequences for humans (Rockström et al., 2009); Figure 4. Identifying and quantifying 'planetary boundaries' that must not be transgressed therefore help prevent human activities from causing unacceptable environmental change.

One of the most – perhaps *the* most – ubiquitous human activity relates to striving to attain food security and from a 'food' perspective agriculture is usually thought of as the cause for concern; 12-14% of total greenhouse gas (GHG) emissions are attributed to agriculture and a further 18% attributed to land-use change and forestry (much of which related to clearing land for agriculture and pasture) (Foresight, 2011). However, all food system activities lead to GHG emissions and Edwards et al. (2009) estimated that in the US food system, only 60% of GHG emissions can be attributed to producing food; 40 % are due to the other food system activities. But GHG emission is not the only environmental consequence of food systems. Impacts on biodiversity, on biogeochemical cycles, on fresh water resources and on other environmental parameters are all in part caused by food system activities (Figure 2).

Table 2 shows a matrix of the four sets of food system activities against eight of the 10 planetary boundaries ('ocean acidification' and 'stratospheric ozone depletion' are not included as they were not quantified).

<Table 2 placed at end of paper>

Rather than being confined to impacts of agriculture, Table 2 gives examples in almost all cells of the matrix; almost all food system activities contribute to 'crossing the boundaries'.

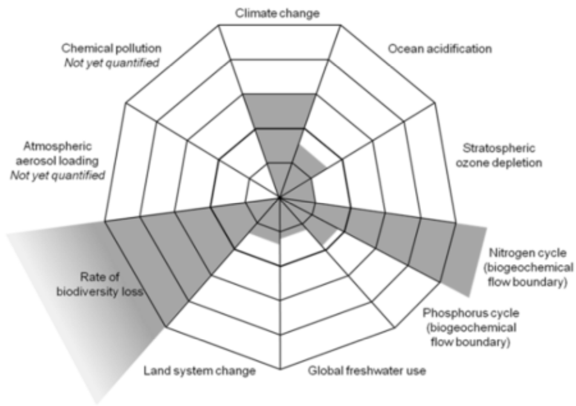

Figure 4 Nine 'planetary boundaries' which, if crossed, could generate unacceptable environmental change (reproduced from Liverman and Kapadia (2010), with permission).

Food processing leads to a range of wastes which exhibit large amounts of organic materials such as proteins, carbohydrates, and lipids; large amounts of suspended solids (depending on the source); high biochemical oxygen demand (BOD) and/or chemical oxygen demand (COD); high N concentration; high suspended oil or grease contents; and high variations in pH. Most have higher levels of these contaminants than municipal sewage (Kroyer, 1995). Food processing plants have been found to be responsible for 4.7% of total manufacturing intake of fresh water (Dupont and Renzetti, 1998).

Food packaging requires paper and card (which both demand land use change for pulp production, with consequences for forestry operations affecting biodiversity and pollution); plastics (which have both high real and virtual carbon contents); and aluminium and steel (which can affect biodiversity through the construction of hydroelectricity schemes for smelting bauxite and iron ore). Transporting food also makes a large direct contribution to GHG emission and the notion of 'food miles' receives considerable attention in the scientific and more general media. Food transport for the UK, for example, produced 19 Mt CO_2 in 2002, of which 10 Mt were emitted in the UK (almost all from road transport) (Spedding, 2007). Over 2 Mt CO_2 is produced simply by cars travelling to and from shops (Food Climate Research Network, 2011). In retailing, refrigerant leakage from fridges and freezers accounts for 30% of super-markets' direct GHG emissions (Environmental Investigation Agency, 2010), while preparing food also contributes significantly to GHG emissions, with 23% of energy use in commercial kitchens devoted to cooking, 19% to water heating and 19% to space heating (CIBSE, 2009).

Finally, it is well worth noting that much of the GHG emission could be reduced across the whole food system if less food was wasted by consumers. Parfitt et al. (2010) report that 25% of food purchased (by weight) is wasted in UK households and the 8.3 Mt of food and drink wasted each year in the UK has a carbon impact exceeding 20 Mt of CO_2-equivalent.

Reducing food waste by only 25% in the USA would reduce CO_2-equivilent by 65 Mt annually (Lyutse, 2010).

Many studies assess the impact of a given food system activity (e.g. producing or transporting food) to a given environmental outcome (e.g. GHG emissions). The food system concept provides a framework to integrate such studies to provide a more complete description of the 'food' contribution to crossing the planetary boundaries.

Example 5: Analysing the food security dimension in international environmental assessments

The final example shows how the notion of a full set of food security outcomes (Box 1) has been used to analyse the completeness of international environmental assessments in regard to food security. As a contribution to the GECAFS synthesis (Ingram et al., 2010), Stanley Wood and colleagues reviewed the goals and outputs of major international assessments that have examined the linkages between environment and food. The analysis included the Millennium Ecosystem Assessment (MA, 2005c), the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment (IPCC, 2007) and Global Environment Outlook 4 (UNEP, 2007). Particular attention was played to the treatment of food systems, as well as to the extent to which the key implications of GEC for global and local food security were articulated and explored (Wood et al., 2010).

Relevant factors were extracted from the three assessments that had been treated in one or more assessments, and which pertained to: environmental conditions; environment-related stresses that have relevance for food system functioning); food system measures of performance; and food security outcomes. These factors are grouped and displayed in the four columns in Figure 5. The figure also indicates the linkages flowing from left (environment condition) to right (food security outcomes) that received attention in the assessments.

While noting their analysis is "inescapably qualitative and subjective in its formulation", Wood and colleagues highlight a number of issues concerning the relative strengths and weaknesses of the assessments undertaken: (i) producing food is the single most dominant food system component and, specifically, GEC-induced impacts on productivity; (ii) many factors identified in the assessments were not explicitly linked to other factors of relevance to food security outcomes (there are fewer linkages moving to the right of Figure 5); (iii) there appears to be systematic biases in knowledge and analytical capacity that are unrelated to the perceived importance of specific factors (e.g. pests and diseases and post-harvest losses are anecdotally very significant factors influencing food availability but they receive relatively little treatment); (iv) issues relating to seasonality and stability receive very little attention; and (v) there are substantial data, knowledge and expertise gaps related to processes influencing the non-supply-related food security outcomes.

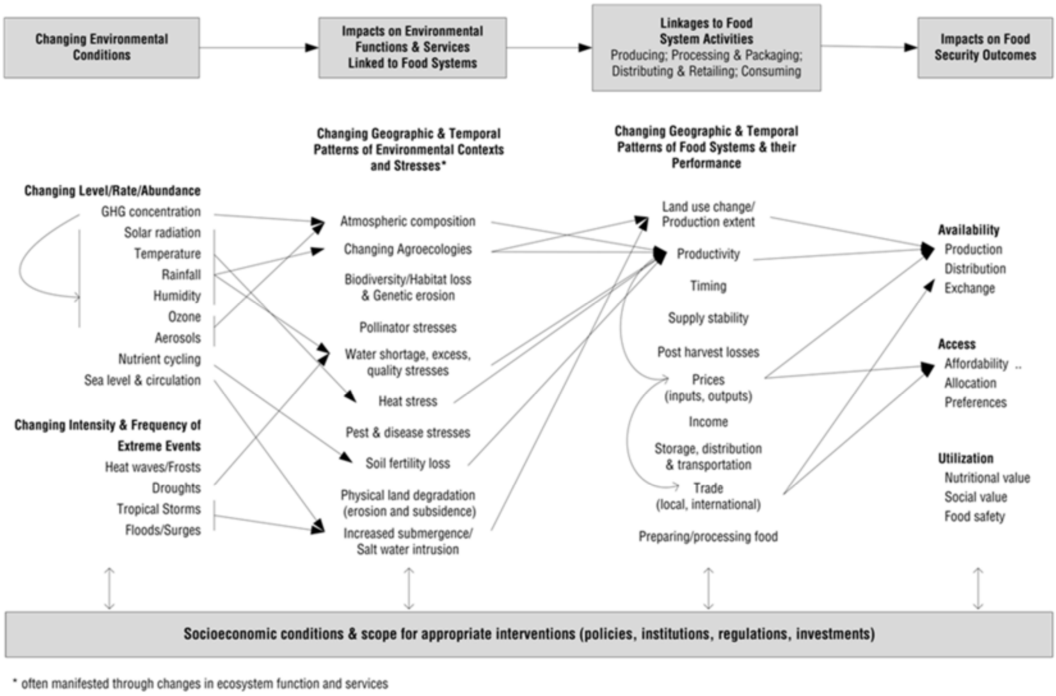

Figure 5 Environmental change, food system, and food security outcome components and dynamics: highlighting concentration of issues and pathways addressed by assessments (reproduced from Wood et al., 2010 with permission).

The food system concept provided a ‘checklist’ to help structure this analysis, revealing assessments have “fallen short, sometimes significantly, of providing comprehensive and balanced evidence on the range and interdependence of environmental change phenomena and on the consequences of change on the many facets of food systems and security” (Wood et al., 2010).

Conclusions

Understanding the interactions between food security and global environmental change is highly challenging. This is nevertheless increasingly important as 50% more food will be needed by 2030 (Godfray et al., 2010b) and there are concerns that the risk of food insecurity will likely grow. These concerns are compounded by the simultaneously need to reduce negative environmental feedbacks from the ways we meet these demands. A further challenge therefore is developing food system adaptation pathways that are significantly more environmentally benign than current approaches. Adapting our food system activities to meet these challenges will give rise to changes in all food security outcomes to some extent (Figure 1) but often researchers only consider one food security element, usually food production. A meaningful adaptation discussion on food security needs consideration of how any intervention will affect all other eight elements of the food security outcomes; in principle, any intervention, even if only targeted at only one element will affect all nine.

More effective policies, practices and governance are needed at a range of levels on spatial, temporal, jurisdictional and other scales (Cash et al., 2006; Termeer et al., 2010) and research has an important role to play in providing knowledge to assist. Given the complexity of food security, and especially in the context of GEC, this research has to develop systematically to be most effective. However, different research groups have differing interests and/or could be addressing differing information need for policy formulation. The overall framework –albeit depicted in general terms – helps to map where each effort contributes to the overall picture. The examples above show how this mapping can occur in practice, each relating to either the food system activities or the food security outcomes, and dealing with different areas of interest (i.e. vulnerability/impacts or adaptation or feedbacks).

When taken together (Figure 1) and considered within (i) the notion of interacting GEC and socioeconomic drivers, and (ii) potentially positive and deleterious feedbacks to socioeconomic and/or environmental conditions (Figure 2), the framework can bring further benefits. First, it provides a checklist to help ensure the necessary issues are included in dialogues aimed at enhancing food security (especially in the context of other goals) and identifies the range of actors and other interested parties who should be involved. Second, it helps assess the impacts of GEC on food systems by focussing on multiple vulnerabilities in the context of socioeconomic stresses. Third, it helps in determining the most limiting factors which lead to food insecurity, thereby identifying intervention points for enhancing food security.

Identifying which of the numerous interactions depicted in Figure 2 to research, and how to bring them together would be highly complex without a framework. Most importantly, therefore, it provides a conceptual model to help identify research avenues for (i) integrated analyses of the full set of food system activities (i.e. producing, storing, processing, packaging, trading and consuming food) with those of the food security outcomes (i.e. stability of food access, utilisation and availability, and *all* their nine elements (rather than just food production); and (ii) analysing feedbacks to the earth system (e.g. GHG emissions, impacts on biodiversity) from food system activities, integrating the "what we do" with the "what we get". By laying out an integrative socio-environmental approach for considering such feedbacks, it thus helps design research to analyse synergies and trade-offs between food security, ecosystem services and social welfare outcomes of different adaptation pathways.

It is important to discuss one final aspect. As mentioned above, the framework is depicted at a general level and cannot, in itself, assess the consequences of specific interventions. Its value is in helping to formulate plausible hypotheses that can and should be further explored through other methods. So, while acting as a checklist of what needs to be discussed, it only identifies a number of high-level issues; some specific issues, such as animal welfare (ESF, 2009) or public attitudes to genetically modified foods, are of high priority in some parts of the world, and would need to be included or strengthened for specific studies. To this end, individual research projects need to establish detailed agendas in the context of the overall framework.

Table 1: Indicative analysis of the method by which (in **bold)** the application of example ITC technologies (in *italics*) in different food system activities (columns) could affect a range of food security outcomes (rows). (From Ingram, Barling and Gobius, unpublished.)

	Producing food	**Processing/Packaging food**	**Distributing/Retailing food**	**Consuming food**
Food Production	*Automated lab experiments and micro arrays in plant technology* to **screen potential traits/genes**	*Sensors and automation* for **better quality control in food processing**		*Web connectivity* to **enable social consumer networks to inform producers**
Food Distribution	*Satellite data, GIS and high performance computing* for **forecasting better crop failure for emergency food aid planning**		*RFID tags* to **improve logistics**	*e-commerce* to **enable internet ordering and instant delivery**
Food Affordability	*GIS for improved input use efficiency* to **reduce costs of production**	*Low cost print technologies* to **reduce packaging costs**		*Web connectivity* to **enable social consumer networks to inform other consumers**
Food Exchange	*Cell phone technology* to **help artisanal fishers find best local market**	*RFID tags* to **improve value chain management**	*Secure e-commerce* to **enable trusted trade data exchange**	
Food Safety		*Smart packaging* for **spoilage identification**	*Sensors and automation* for **monitoring cold chain and storage conditions**	*Low cost detection kits* for **scanning for food contaminants**

Table 2: Matrix giving examples of how the four sets of food system *Activities* (columns) contribute to crossing eight of the 10 planetary boundaries (rows)

	Producing food	***Processing & Packaging food***	***Distributing & Retailing food***	***Consuming food***
Climate change	GHGs from fertilizers; changing albedo	GHGs from energy production	GHGs from transport and refrigeration systems	GHGs from cooking
N cycle	Eutrophication and GHGs from fertilization	Effluent from processing and packaging plants	NOx emissions from transport	Food waste
P cycle	P mining for fertilizers	Detergents from processing plants		Food waste
Fresh water use	Irrigation	Washing, heating, cooling		Cooking, cleaning
Land use change	Extensification and intensification	Deforestation for paper/card	Transport and retail infrastructure	
Biodiversity loss	Deforestation, hunting, fishing	Hydroelectricity dams for aluminium smelting	Invasive species	Consumer choices
Atmospheric aerosols	Smoke and dust from land-use change		Emissions from shipping	
Chemical pollution	Pesticides	Effluent from processing and packaging plants	Transport emissions	Cooking, cleaning

From Food Production to Food Security:
Developing interdisciplinary, regional-level research

Part III: The case for region-level research and broad stakeholder engagement

Paper 4: Why regions?

Adapted from:

Liverman, DM and JSI Ingram. 2010. Why regions? pp 203-210 In: *Food Security and Global Environmental Change*. JSI Ingram, PJ Ericksen and DM Liverman (Eds). Earthscan, London.

Paper 5: Engaging stakeholders at the regional level

Adapted from:

Ingram, JSI, J Andersson, G Bammer, M Brown, K Giller, T Henrichs, J Holmes, JW Jones, R Schilpzand and J Young. 2010. Engaging stakeholders at the regional level. pp 169-197 In: *Food Security and Global Environmental Change*. JSI Ingram, PJ Ericksen and DM Liverman (Eds). Earthscan, London.

Paper 6: Undertaking research at the regional level

Adapted from:

Ingram, JSI and A-M Izac. 2010. Undertaking research at the regional level. pp 221-240. In: *Food Security and Global Environmental Change*. JSI Ingram, PJ Ericksen and DM Liverman (Eds). Earthscan, London.

Paper 4: Why Regions?

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Introduction

Global environmental change (GEC) science has traditionally been studied as separate parts of the Earth system. These include physical and biophysical aspects (e.g. the climate sub-system, the oceanic sub-system, the carbon cycle, etc.) and social, economic and/or political dimensions, which are particularly important when studying the drivers of change. An alternative approach is to study how these functional aspects interact in sub-global geographical regions. Regions are a natural level for such analysis, and especially for studies of social-ecological systems (such as food systems) as – while clearly not homogenous in all ways – they are often defined by shared cultural, political, economic and biogeographical contexts (Tyson et al., 2002a).

The term 'region' is, however, ambiguous. At the coarsest level, the United Nations (UN) defines regions as continents (e.g. Latin America and the Caribbean, LAC – although this level of aggregation can produce its own problems, with many Caribbean nations often preferring not to be 'lumped in' with Latin America) but there is no standard way of dividing the world into regions. However, the term can also be used within a given continent and, in the case of Africa, official UN regions are Northern, Western, Eastern, Southern and Central. Similarly, the African Union has established seven Regional Economic Communities as the key pillars of economic cooperation within the continent. Africa has also been divided into large regions based partly on physical geography such as the Sahara and Sahel (comprising the vast western African desert and the region bordering it to the south), the Horn of Africa (with Ethiopia, Eritrea and Somalia) and the central African Congo (defined around the river basin or the forest). Even within a country the term is used to define formal administrative units (e.g. France is divided into 22 formal regions).

Geographers often point out that regions are 'socially constructed' as ways to organize the world according to perceptions, race and cultural identity, or colonial aspirations for example (MacLeod and Jones, 2001). Such regions can change such as when, for example, the collapse of the Soviet Union resulted in several countries (e.g. Poland and Lithuania), which had traditionally been classified in the Soviet region, shifting their affiliation and regional grouping to Europe. Political scientists have also noticed how the rise of regional political and economic projects such as regional trade associations (e.g. the North American Free

Trade Agreement (NAFTA) and the European Union) have created newly constructed regions (Hettne and Söderbaum, 2000).

These inconsistencies in terminology make it more difficult to address resource and governance issues and call for clarity when using the term ‘region’. For global change studies – and as is the case for this book – ‘regional’ is usually taken to mean the sub-continental, but supra-national, level; the International Geosphere-Biosphere Programme (IGBP) synthesis *Global-Regional Linkages in the Earth System* (Tyson et al., 2002a) considered regions as being southern Africa, South Asia, South-East Asia and East Asia.

Importance of the regional level

‘Regional’ is an important spatial level for food security, food system research and GEC considerations for several reasons.

First, regions make sense in terms of environmental change. We organize our understanding of the world around biophysical classifications that include, at a regional level, ecosystems and river basins. Examples of regional-level ecosystems include grasslands (e.g. of southern Africa and the North American Great Plains), which often convert to rangeland regions for livestock or grain production areas, or tropical forests (such as the Amazon). Agro-ecological zones often map onto these regions of common physical characteristics. Large river basins comprise regions linked by the flows of water and sediment that are often the basis for irrigated agriculture. This physical coherence of regions is the basis for environmental and food system data collection at the regional level such as Agrhymet in West Africa). Climate and weather-related perturbations often occur at the sub-continental level with major droughts and natural disasters, for example, often spanning large areas. Pollution often affects large regions as contaminated air and water easily cross national borders.

Second, regions can have strong cultural dimensions. Proximity and common ecologies, and physical geographies, are sometimes associated with coherent cultural regions with common language, economies and social practices including food systems that have strong regional cultural characteristics. Examples include regions of the Mediterranean (such as Tuscany) or rice cultures of Asia such as those found in Indonesia or China. If the biophysical environment of these regions alters it can create cultural stresses, and when food systems change that can change the physical landscape as land use changes, for example. Shared cultural traditions can be the basis for land managers with strong regional interests and identities organizing to protect landscapes and food systems.

Third, regions can be useful units for government and governance. Regional governance structures have been established in many parts of the world, such as the EU, or the Southern African Development Community (SADC). Such structures offer a ‘client’ for GEC/food security research, and indeed, the jurisdictional mandate of such bodies can be used to help define the geographical scope (i.e. spatial level) for a GEC/food security study. Regions have also become an appropriate spatial level for organizing peacekeeping or military security (especially in the aftermath of conflict) and/or for managing shared resources. A good example is in the Mekong river basin where the governments of Cambodia, Lao PDR, Thailand and Vietnam formed the Mekong River Commission (MRC) to jointly manage their shared water resources and development of the economic potential of the river. The emergence of regional governance is an important reason to consider food security and environmental interactions at the regional level. In some cases, colonial powers imposed national boundaries that divided cultures and ecosystems, creating conflict or barriers, to, for example, regional mobility in response to climate variability.

Finally, intraregional trade can be significant. The friction of physical distance (e.g. transport costs, perishability) means that, where long-distant transport infrastructure is less well developed, trade is often most effective at the regional level and can enhance food security through improved intraregional trade, strategic food reserves and transport facilities. The emergence of megacities can restructure trading systems to focus food systems across a large region on provisioning urban centres such as Mexico City or Beijing.

There are, however, challenges in taking a regional approach. While many natural science issues have been addressed at the regional level for some time, social science theories, methods and data have traditionally been better developed at the micro- or macro-levels (Rayner and Malone, 1998). This is perhaps surprising given that governance, for instance, is often central to the widespread water-related issues (e.g. the MRC example, above). Indeed, one of the effects of the rapidly increasing population and growing fears of conflict over water, has been the emergence and proliferation of 'a montage of water-related associations, programmes and organizations', what Varady and Iles-Shih (2009) refer to as *global water initiatives*. However, as they go on to say, "because these institutions have sprung from numerous and often divergent sources, attempts to develop innovative and practical observations and recommendations have sometimes been frustrated by the sheer number of voices and diversity of approaches continually emanating from this dynamic institutional 'ecosystem'".

Nonetheless, as Wolf et al. (2003) note, 'the record of acute conflict over international water resources is overwhelmed by the record of cooperation' and that 'overall, shared interests, human creativity and institutional capacity along a waterway seem to consistently ameliorate water's conflict-inducing characteristics'. So, while the example of water management at regional level shows the potential benefits of undertaking integrated approaches (and research to support them), it is not straightforward and there is still a relative lack of studies of the social-ecological dynamic encompassed in food systems at this level.

Overcoming the mismatch between disciplinary fields at different spatial levels is, however, crucially important, as it will help fill a research gap between the many sub-national and national analyses of food production and food security (as conducted by national governments and the UN, for instance) and those at the global level (e.g. Fischer et al., 2005;

Parry et al., 2005). Conducting food system research at the regional level also means that it can address both rural and urban issues, and the relationship between them. Data collection is also a challenge at regional levels if the region of interest includes parts, but not all of several nations because data, especially economic and social, is often collected at the national level and data systems may vary between countries.

GEC/food security research at different scales and levels

There have been a large number of experimental studies under the ‘food security’ banner addressing food production. Most have addressed crop or animal productivity (i.e. yield), and have reported research conducted at the experimental plot level (i.e. very local) over a growing season or perhaps a few years. However, many of the issues related to regional food production, and even more so to regional food security, operate at larger spatial and temporal levels, and warrant further research.

Aware of the need for better links between agronomic research on crop productivity at plot level and regional production, and especially over time, the last decade or so has seen agronomists beginning to establish trials at landscape level (e.g. Veldkamp et al., 2001). Estimating regional production is not however just a matter of ‘scaling up’ plot-level agronomic trials as the critically important social and institutional processes operating at higher levels need to be factored in. Put another way, studies that scale up from plot to regional level can be misleading at best and could lead to actions that impede real progress toward food security unless social and economic components are at the heart of the process. Hence, a considerable methodological challenge to be overcome at such levels is for agronomists to work more effectively with economists and social scientists, as well as with system ecologists, to capture the key economic and social processes, as well as biophysical and ecological processes at play at different spatial levels (Ingram et al., 2008). This includes not only adopting a more interdisciplinary approach but also analysing interactions among variables from one level to the other. For instance, a decrease in maize yield at the plot or field level may lead farmers to decide to shift to other crops (e.g. beans or cassava). If the shift is significant at the regional level, changes in the price of maize versus that of the alternative crops will take place. These changes in relative crop prices will trigger further changes in farmers’ practices and in their adaptation of their systems to the market (Ingram et al., 2008). In contrast to agronomic studies, agricultural economic studies have often undertaken analyses at higher spatial levels, especially on economic and market implications, e.g. the Institute Food Policy Research Institute’s (IFPRI) IMPACT model (as discussed by Rosegrant and Cline, 2003).

Crop modellers have meanwhile been running simulations of crop yield over large areas for some time. Early approaches (e.g. Rosenzweig and Parry, 1994) used point-based estimates scaled-up using climate model output (which is only available at the higher level). More recent studies (e.g. Parry et al., 2005; Challinor et al., 2007) do model crop response at higher levels, but as they stress the influence of weather and climate, and their basis in observed relationships, large-area crop models do not currently simulate the non-climatic determinants of crop yield. These non-climatic stresses contribute to the yield gap (Challinor et al., 2009), i.e. the gap between potential and actual yields. However, as such models do not encompass changes in the proportion of land under cultivation, it is not possible to estimate how regional production will actually change. Certainly, reliable information is needed on plot-level responses to environmental stresses that can be scaled up geographically, but not in isolation from the other major regional drivers of food systems. Coupling models at different spatial levels from plot to region allows the study of interactions and feedbacks among biophysical and social components at different levels. There is therefore a need to design interdisciplinary research that starts with GEC objectives at a regional level, and to build systems that facilitate better understanding of these interactions and feedbacks. The suit of 'point' (or plot-level) crop models now available (e.g. DSSAT, APSIM, SUCROS) provide a valuable foundation for such work. Regional-level studies can be greatly facilitated, and very useful information provided to social and economic models, when the point models are integrated with downscaled climate model results.

Other modelling studies at regional level address how 'mega environments' for major crops will change (e.g. for wheat, Ortiz et al., 2008b); and how the biogeography of major and locally important crops, and crops' wild relatives will be affected (e.g. Jarvis et al., 2008). Cross-scale and cross-level interactions are not, however, generally included in modelling studies, other than where a spatial scale issue has direct relevance, as is increasingly the case for multi-scale scenario studies (Ingram and Izac, 2010: Paper 6).

In addition to considering 'up-scaling' research on food production, there is a need to also consider research at more integrated levels for other aspects of the food system. Food storage is another key determinant of food security, and is especially important during times of stress. It is, however, a complex issue, crossing a number of levels on spatial, temporal and jurisdictional (and possibly other) scales. While research has addressed the issue of strategic food reserves at village level (e.g. Mararike, 2001) and national level (e.g. Olajide and Oyelade, 2002), there is insufficient research into how best to establish long-term food reserves at regional level. These could be a highly effective means of coping with impacts of major droughts or other stresses that manifest at the regional level, but the issues are often highly charged politically and progress can be slow. For instance, since the 1980s, SADC has considered the establishment of a strategic food reserve to deal with the growing frequency of natural disasters. Early proposals were based on considerations of enough physical maize stock for 12 months' consumption, but the SADC Council of Ministers have only recently agreed that the food reserve proposal should be revisited and should include consideration of both a physical reserve and a financial facility, supporting the notion of enhanced intraregional trade (Drimie et al., 2011).

Other food system activities such as food distribution and logistics and consumption patterns also warrant further analysis at regional level. An example of an initial analysis of current knowledge and future research needs of all the major activities of the European food system is provided in the ESF/COST Forward Look on 'European Food Systems in a Changing World' (ESF, 2009).

Cross-scale and cross-level interactions for food security

The importance of scales and scaling as determining factors in many environmental and food security problems is discussed in Chapter 2. In terms of food security management, cross-scale (e.g. space, time) and cross-level (e.g. local–global; annual–decadal) interactions are crucial and have to be central to the formulation of food security policies. In general, there are three situations in which combinations of cross-scale and cross-level interactions threaten to undermine food security (Cash et al., 2006):

- *Ignorance*: the failure to recognize important scale and level interactions in food systems, e.g. distress cattle sales that reduce national price.
- *Mismatch*: the persistence of mismatches between levels and scales in food systems, e.g. food security responses planned at national level versus community level.
- *Plurality*: the failure to recognize heterogeneity in food systems in the way that scales are perceived and valued by different actors, even at the same level, e.g. local food aid programmes versus local social safety nets.

As Cash et al. (2006) note, there is a long history of disappointments in policy, management and assessment arising from the failure to take into account the scale and cross-scale dynamics in social–environment systems. For instance, the management of food systems, and the food security they underpin both over time and space, is an excellent example. Regional-level studies, especially when based on an awareness of the potential risks of ignorance, mismatch and plurality, can help identify impediments to achieving food security. This also helps to frame new research questions of direct relevance to policy formulation, for example, How would interactions among rules, laws and constitutions affect food system adaptation at different spatial levels? (cross-institutional/spatial scales issues); How would short-term changes in donor philosophy on food- or seed-aid as applied at the local level affect long-term regional self-reliance? (cross-time/management scale issues); or How would implementing different short-term adaptation policies in different nations influence regional food security goals? (cross-jurisdictional/management scales issues). Box 1 gives a case study of scale challenges of ignorance, mismatch and plurality in relation to the distribution of emergency food aid in the 1991/92 drought in southern Africa. The situation was exacerbated by the legacy of colonial investment in transport infrastructure which concentrated on communication lines to main ports rather than more generally within the region and between countries.

Box 1 Example 'scale challenges' related to distribution of emergency food aid in the 1991/92 drought in southern Africa.

In 1991/92 southern Africa experienced one of its worst droughts, with 2.6 million square miles stricken, 86 million people affected; 20 million people at 'serious risk', and 1.5 million people displaced. In response, the international community shipped millions of tonnes of food aid to the region, with the plan to distribute to the hinterlands along six 'corridors' from the region's main ports: Dar es Salaam, Nacala, Beira and Maputo, Durban, Walvis Bay and Luanda. While many lives were saved, the overall effort was severely frustrated by a number of scale challenges.

Ignorance

- National toll and quarantine policies vis-à-vis donor approach: *the regional response strategies to move food around the region seemed ignorant of the range of different national policies thereby delaying moving relief food across international borders.*
- Global response vis-à-vis poor regional port management: *the massive international aid operation erroneously assumed the region's ports could unload and forward on food aid in large amounts.*

Mismatch

- Jurisdiction of the national institutions is not coterminous with supplying food to the region: *national institutions were not equipped to arrange the distribution of food at the regional level.*
- Urgency of food need poorly matched with institutional response speed: *the institutions charged with managing the crisis were unable to act at the rate needed to satisfy demand.*

Plurality

- Conflict between humanitarian requirements and commercial concerns: *the suppliers of transport and other infrastructure were usually businesses, not relief agencies.*
- Variety of objectives among donors, recipients and regional institutions: *the different objectives of many actors involved in the relief effort were not necessarily synergistic.*

Conclusions

The two-way interactions between GEC and food security manifest at the full range of spatial levels from local to global. To date, however, almost all studies have tended to focus on these two extreme levels and information for sub-global (continental or sub-continental) geographical regions is sparse. This is despite the fact that a range of options for adapting food systems to GEC and other stresses only become apparent when a regional viewpoint is adopted (e.g. regional strategic grain reserves, harmonized tariffs and taxes or regionally managed water resources). Further, sub-global is a natural level for studies of social–ecological systems (such as food systems) as – while clearly not homogenous in all ways – they are often defined by shared cultural, political, economic and biogeographical contexts.

Research at regional level can thus offer a range of benefits to researchers, policy-makers, natural resource managers and other stakeholders and warrants receiving more attention in the GEC/food security debate.

Paper 5: Engaging Stakeholders at the Regional Level

Adapted from:

Ingram, JSI, J Andersson, G Bammer, M Brown, K Giller, T Henrichs, J Holmes, JW Jones, R Schilpzand and J Young. 2010. Engaging stakeholders at the regional level. pp 169-197 In: *Food Security and Global Environmental Change*. JSI Ingram, PJ Ericksen and DM Liverman (Eds). Earthscan, London.

Introduction

Food security in the face of global environmental change (GEC) is one of the most complex issues facing the research community at large. Although most policy-makers, scientists and funding agencies recognize the need for additional knowledge about how the various food system activities interact and how these interactions affect food security, research that is capable of adequately addressing the problem is hard to find. This is because not only are there large uncertainties in many aspects of the debate, but the debate involves a bewildering range of interested parties, or 'stakeholders'. A further complication is that food systems involve critical interactions at a number of levels on a range of scales (e.g. spatial, temporal, jurisdictional, institutional, management) (Cash et al., 2006), each of which has its own group or groups of stakeholders. Research on the interactions between GEC and food security therefore has to recognize, and engage with, a wide range of stakeholders. This is in contrast to research on crop improvement, for instance, where the range of stakeholders is much narrower, and may remain predominantly within the research community itself. While considerable effort has been spent in improving understanding of food system-GEC interactions at the local or household level, research at the regional (sub-continental) level is far less well developed, but offers important insights into food system adaptation strategies and policies. This paper therefore addresses stakeholder engagement at regional level.

Clearly, aligning the research agenda with stakeholder needs is crucial and this requires effective dialogue (for example through consultancies, agenda-setting workshops and/or informal processes). Equally important however is the uptake of research results by the intended beneficiaries that leads on to the real value of the research. This similarly depends on continued interactions between researchers and other stakeholders. However, as stakeholder involvement complicates the research process and increases costs for all concerned, it is it important to understand its importance and the value it can bring throughout a given project.

As Kristjanson et al. (2009) summarize, it is important to see stakeholder engagement as an integral aspect of both the conceptualization and the life of the project. They stress the value of articulating the outcomes sought by the different stakeholders at the project outset to help bring the different actors toward a joint understanding of the overall project goals and come up with innovative strategies to achieve them (see Box 1). This also serves to give interested parties a tangible stake in the outcome. These aspects of research agenda alignment and uptake of outputs derive from what is a double aim of the stakeholder dialogue. The first aim concerns the formal agenda-setting. If the research is to have impact it is crucial that it both addresses the information needs of the intended beneficiaries, and is scientifically valid. The second aim is that of a social support function that helps all stakeholders feel involved and heard. While less obvious, this aspect is no less important as effective stakeholder engagement needs to be built on trust between all concerned, which will encourage uptake of research outputs. This may be especially the case at the regional level as stakeholders may well be senior individuals with specific agendas, and in these circumstances it is crucial to be clear about whether researchers are acting as advocates or honest brokers (Holmes et al., 2010). This social support aspect also allows researchers to obtain a better 'feel' for the context within which the research is to be conducted.

Box 1 Seven propositions/principles for 'linking knowledge with action' (adapted from Kristjanson et al., 2009).

1 Problem definition

Projects are more likely to succeed in linking knowledge with action when they employ processes and tools that enhance dialogue and cooperation between those (researchers, community members) who possess or produce knowledge and those (decision-makers) who use it, with project members together defining the problem they aim to solve.

2 Program management

Research is more likely to inform action if it adopts a 'project' orientation and organization, with leaders accountable for meeting use-driven goals and the team managing not to let 'study of the problem' displace 'creation of solutions' as its research goal.

3 Boundary spanning

Projects are more likely to link knowledge with action when they include 'boundary organizations' or 'boundary-spanning actions' that help bridge gaps between research and research user communities. This boundary-spanning work often involves constructing informal new arenas that foster user-producer dialogues, defining products jointly, and adopting a systems approach that counters dominance by groups committed to the status quo. Defining joint 'rules of engagement' in the new arena that encourage mutual respect, co-creation and innovation improves prospects for success.

4 Systems integration

Projects are more likely to be successful in linking knowledge with action when they work in recognition that scientific research is just one 'piece of the puzzle', apply systems-oriented strategies, and engage partners best positioned to help transform knowledge co-created by all project members into actions (strategies, policies, interventions, technologies) leading to better and more sustainable livelihoods.

5 Learning orientation

Research projects are more likely to be successful in linking knowledge with action when they are designed as much for learning as they are for knowing. Such projects are frankly experimental, expecting and embracing failures so as to learn from them throughout the project's life. Such learning demands that risk-taking managers are funded, rewarded and regularly evaluated by external experts.

6 Continuity with flexibility

Getting research into use requires strengthening links between organizations and individuals operating locally, building strong networks and innovation/response capacity, and co-creating communication strategies and boundary objects/products.

7 Manage asymmetries of power

Efforts linking knowledge with action are more likely to be successful when they manage to 'level the playing field' to generate hybrid, co-created knowledge and deal with the often large (and largely hidden) asymmetries of power felt by stakeholders.

Who are the stakeholders in the GEC–food security debate?

The term *stakeholder* is now commonly employed to denote 'all parties with a voluntary or involuntary legitimate interest in a project or entity' (Brklacich et al., 2007). For issues of food security, in addition to those involved in the food system activities *per se* (e.g. food producers, processes, packers, distributors, retailers, consumers), stakeholders include funding agencies, national/regional policy agencies, non-governmental organizations (NGOs), civil society groups, business (and increasingly the energy sector, as opposed to biofuels), individuals and communities affected by GEC, and the researchers themselves. For research projects that involve a significant natural resource management component at the local level (as is often the case in field-based, food production research), the resource managers (who are often, but not exclusively, farmers, fishers, pastoralists, etc.) themselves are usually critically important stakeholders. Indeed, methods and approaches for identifying and engaging farmers in the research process, especially in the development agriculture arena, have given rise to a wide body of literature (Chambers et al., 1989; Okali et al., 1994; Martin and Sherington, 1997; Haggar et al., 2001; Ortiz et al., 2008a).

The initial problem facing researchers is to identify who the other stakeholders are, that is, with whom researchers should aim to engage. This can be helped by being clear not only on who the intended target or beneficiary groups are (e.g. impoverished smallholder farmers; urban communities) but also on how food security research is intended to assist them. This means establishing by what route, and mediated by which institutions and structures, the research output will bring about benefit. Because of this it is key actors in *these* domains (e.g. regional policy-makers, donors) who may actually be the more important stakeholders for a given research project than the ‘target’ beneficiaries themselves; in other words, benefit for the ‘target’ beneficiaries would come about through the development of better policies at the regional level. (It is useful to note the value of the role of funding bodies in facilitating the making of these important connections as part of the funding process.)

For research at higher levels of integration on a number of different scales (e.g. spatial, political, jurisdictional) and particularly regarding food security policy (as opposed to food production), it is perhaps not appropriate to include individual farmers as stakeholders in the research process. However, as they (together with other members of society) are obviously among the ultimate beneficiaries of the research effort, it may well be appropriate to engage with regional organizations that represent farming groups, as this can help ensure the interests and constraints of the farming community are included in research design. Thus, in the case of GECAFS research in southern Africa, the formalization of collaboration with the Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN, which comprises national farmers’ organizations; www.fanrpan.org) proved useful in this regard.

For food security research at regional level it is possible to identify four main stakeholder categories: research, government, business and civil society. As food security is a multi-factor issue, no single stakeholder has the complete answer or the power and the tools to realize the changes that will be needed. Cooperation between those involved in these stakeholder communities is required. Stakeholder dialogue necessarily plays an important role (van Tulder and van der Zwart, 2006) and can contribute to agenda-setting, the analysis of a given situation and to the creation and implementation of solutions. However, the fact that none of the stakeholders can be successful without the others presents a strong argument for further intensification of the dialogue process, going beyond consulting and informing each other (i.e. stakeholder dialogue), toward co-production of knowledge and shared responsibilities (i.e. stakeholder engagement) (Rischard, 2001; Henrichs et al., 2010). This requires multidisciplinary research teams coming together with other stakeholders to work on specific problems in the ‘real world’ (Gibbons et al., 1994). It must be noted however that stakeholders play a multitude of different roles in the food system. They often have different goals and agendas that may appear to be (or really are) conflicting.

A further complication is that food systems are inherently multi-scale and multi-level and the non-spatial scales are very relevant to food security/GEC interactions (Ericksen et al., 2009). Different stakeholders operate on different scales and levels; scale and level need to be clearly specified in research engagement activities. Identifying a discrete list of stakeholders for a given situation is therefore far from simple, and the notion held by many researchers of ‘engaging with stakeholders’, while well intentioned, needs to be approached with awareness of the nature and magnitude of the task and especially when working at more local levels (see Box 2). Indeed the success of the project can depend very much on how this stakeholder engagement is envisioned and implemented, and who is at the table.

Box 2 Engaging with stakeholders in the Competing Claims programme.

Too often, researchers blithely refer to involving ‘all stakeholders’. And perhaps even worse, attempts are made to bring all stakeholders together in ‘multi-stakeholder platforms’. This may be a valid approach when the issue at stake is relatively simple and has few stakeholders, but when the stakes are high and cultural differences run deep, meetings can precipitate or exacerbate conflict rather than resulting in useful dialogue. In work in southern Africa on ‘Competing Claims on Natural Resources’, focus is on food security as one important aspect of rural livelihoods that cannot be seen in isolation from other livelihood pursuits (see www.competingclaims.nl). A key concept in the approach is that local problems need to be addressed at multiple hierarchical levels to enlarge the ‘solution space’ within which new opportunities can be sought.

Identifying stakeholders at the higher levels in a hierarchy is simpler by definition – there are fewer players to choose from. When engaging with rural people, initial engagement must inevitably start through local officials and village leaders, though it should not be naïvely assumed that they represent the position of the majority. In particular the poorest and most disadvantaged are the last to contribute in meetings, if they attend at all. Experience shows that it is not possible to develop a rulebook, or a standard set of methods that will work in all settings. What is critical is having an ear close to the ground, and taking time to identify marginal and excluded stakeholders and understand the positions of the different stakeholders *before* bringing them together to discuss issues at stake.

A further issue is the legitimacy of the ‘outsider’ researcher in local debates and problems, and this may be particularly apt in cross-cultural settings. Collaboration with local researchers, NGOs or other development agencies is necessary, but often leads the researcher to become – unwittingly – associated with such local stakeholders, compromising his/her legitimacy for another set of stakeholders. The political neutrality of the researcher is a fallacy, because already research questions tend to be posed by some parties rather than others, and inherently build on specific societal problem definitions, values and aspirations. A transparent yet rigorous approach which makes the stakes explicit is a more modest, yet realistic, approach towards becoming legitimate.

The only general rule to be drawn is that there are no quick and clean methods of identifying stakeholders. It takes time and commitment to gain useful insights, build legitimacy among stakeholders, and to contribute to development. These issues are further discussed by Giller et al. (2008).

Finally, it is also worth noting that some key stakeholders (e.g. the business community) may sometimes be missing from the debate, and it is important to try to identify why this is the case. Is it that they cannot afford the funds or time to become engaged; or they are not allowed to be involved (perhaps for political reasons); or they are simply not interested? It is also important to try to determine the impact of their absence, and what – if anything – can be done to compensate. Certainly, given that stakeholder participation can sometimes be seen as an automatic requirement, taking on something of a ‘tick-box’ culture, some potentially important stakeholders may need to be persuaded to join the debate, especially if they are jaded from earlier, ineffective or disingenuous experiences. To overcome this challenge it is important to stress the benefits that engagement will bring to the stakeholder (rather than the benefits their engagement will bring to the researcher/project): how will engagement help them in their policy or business or funding planning? Ideally, reluctance should transform into a commitment to engage.

Who sets the GEC–food security research agenda, and how?

Basic research is typically disciplinary-focused, often undertaken by relatively small groups of researchers. There may be little need to engage with beneficiary groups, even if the ‘end of pipe’ research outputs are anticipated to be of some practical use. The more involved approach needed to address the broader issues of food security will lead to research being conducted within a more complex context. This might well be characterized by multiple biophysical and social scientific issues, a high degree of uncertainty, value loading and a plurality of legitimate perspectives of the varied stakeholders. Researchers trained in a given discipline which, on the face of it, addresses directly the issues they are investigating can well find themselves confronted by a range of issues in which they have no experience or training. Indeed, stakeholder engagement in the way being discussed here, and especially at the regional level, is not the norm for GEC science endeavours.

In the ‘classic’ GEC research project typical of the international GEC research programmes, a science plan is conceived by the scientists and published. This lays out the research need (as perceived by the research community) in terms of science output, and the relevance to the policy process and resource management is often of less importance. Where relevance to policy is indicated, it usually relates to the global level such as the United Nations Framework Convention on Climate Change or other international conventions.

By contrast, the agriculture and food security research communities have been working with partners on the ground, farmers, policy-makers and other non-research stakeholders for many years, and lessons learnt have much to offer researchers addressing the interactions between GEC and food security.

Due to the complex nature of both GEC and food security, GEC–food security research can be of greater value to stakeholders if set within the regional context and tailored to the needs of regional policy-makers, NGOs, businesses and resource managers. Setting a research and region-specific agenda that is relevant to regional (as opposed to global and/or generic) issues needs a highly consultative and inclusive approach. Further, when conducted in regions of the developing world, the links to the development agenda, and particularly to the Millennium Development Goals, must be explicit. This necessarily means a stronger link to the development donor community, who are not traditional funders of GEC research. Again, lessons learnt by the agriculture and food security research community have much to offer. Box 3 shows the main steps in agenda-setting within GECAFS regional studies.

Box 3 Setting the research agenda for regional GECAFS studies (GECAFS, 2005).

An important aspect of the GECAFS regional approach has been to ensure that the research agenda closely matches major *regional* GEC science interests (as distinct to 'international' interests), policy needs and donor priorities. The process to achieve this constituted the planning phase for each regional project (southern Africa, the Caribbean and the Indo-Gangetic Plains) and involved workshops, informal conversations and discussions with a wide range of potential stakeholders in the region. In each case it culminated in the region's GECAFS Science Plan and Implementation Strategy.

The development for each region followed a common approach. Figure 1 shows the main steps in the planning phase (Steps 1–3) and subsequent implementation phase (Steps 4–6).

Step 1 Working with GECAFS Scientific Advisory Committee (SAC) members, other GECAFS International Project Office (IPO) contacts and IGBP (International Geosphere-Biosphere Programme), IHDP (International Human Dimensions Programme) and WCRP (World Climate Research Programme) National Committees within the region, identify regional scientists likely to be interested in the GECAFS interdisciplinary approach and establish a GECAFS initial regional planning group. This group aimed to include members from the research, policy, NGO and private sectors.

Step 2 Working with the initial regional planning group, identify regional science, policy and potential donor interests and information needs.

Step 3 Working with the initial regional planning group, and with other stakeholders, establish GECAFS regional research questions, develop and publish the GECAFS regional Science Plan and Implementation Strategy, and establish a Regional Steering Committee.

Step 4 Working with the Regional Steering Committee and joined by Core Project/ESSP (Earth System Science Project) representatives as appropriate, establish regional research/Core Project/ESSP collaboration and jointly design and implement GECAFS analyses.

Step 5 Working with regional scientists and the policy community, and Core Project/ESSP representatives as appropriate, deliver and interpret GECAFS results in policy context.

Step 6 Integrate results across GECAFS studies in other regions to develop (i) improved generic understanding of food systems and their vulnerability to GEC, (ii) scenarios methods and (iii) improved decision support.

GEC–food security research agenda-setting must aspire to build a number of bridges that traditional GEC science has not well addressed. It must bridge natural, social and economic sciences; science and policy, and other stakeholders' interests; and science and development. It must also relate to the interests of each group of stakeholders. This is challenging, as it necessitates spanning disciplines, research cultures, funding modes, and even attitudes and perceptions of what constitutes science and GEC research. In fact, although often thought to be a particular problem in the developing world, the issues surrounding GEC–food security research agenda-setting are complex the world over. There are a number of reasons for this.

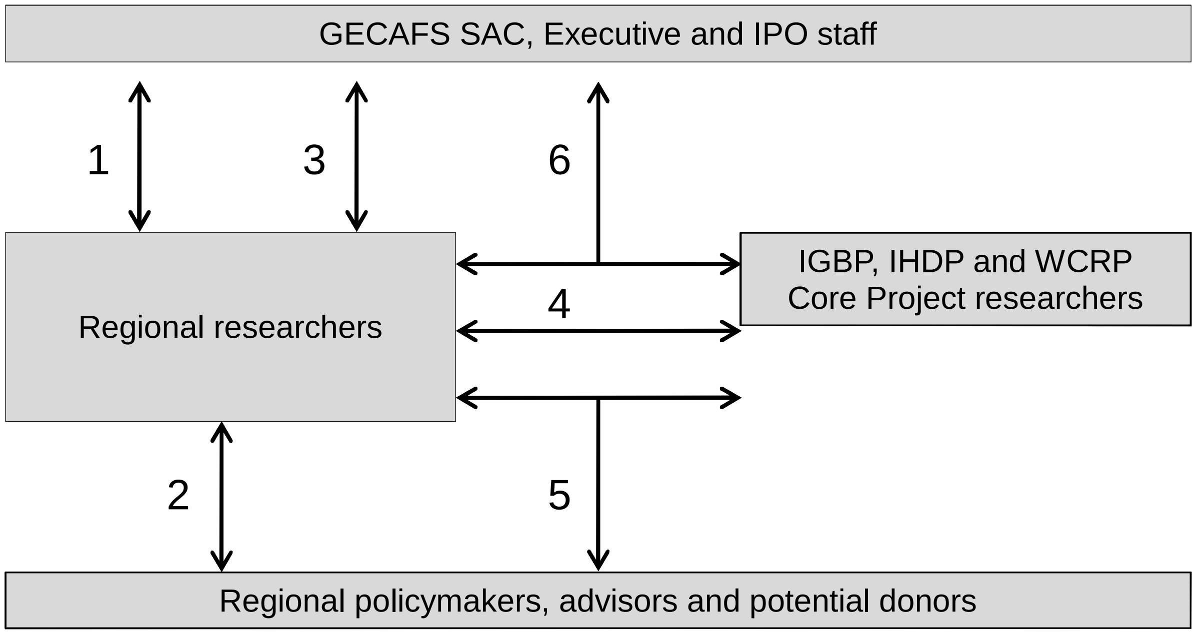

Figure 1 Key steps in design (Steps 1-3) and envisaged implementation (Steps 4-6) of GECAFS regional food systems research (from GECAFS, 2005).

First, food security involves many more issues than food production alone, and a wide range of disciplines have to be integrated to understand the full suite of issues: economics, anthropology, sociology and engineering sciences are, for example, as important as crop, animal and agronomic sciences. In the research community, biophysical scientists often assume the lead on agenda-setting for food security research, and other researchers from the social sciences of equal relevance can be left out. Alternatively they may be invited in after the main (and often quite detailed) elements of research are decided upon; 'bolting on' social science to what is essentially a biophysical agenda generally does not work well! In contrast, the development community generally tries to take a more balanced interdisciplinary approach in agenda-setting. While outputs from disciplinary research endeavours are essential building blocks, the GEC–food security agenda must emerge from a balanced dialogue between researchers across social and natural sciences, and include other stakeholders as appropriate.

Second, the range of scales and levels pertaining to food security, and interactions between them, pose particular challenges for the GEC-food security agenda. Raising the bar from agenda-setting, which traditionally addresses agronomic issues at plot- or farm-level for a given growing season, to one addressing food security for a nation or even sub-continental region over time, is daunting. Researchers have to develop, accept and work within new conceptual models and frameworks, and relate these to policy and resource management considerations with which they are unfamiliar, and often uncomfortable.

Third, and of considerable practical relevance, GEC research is usually thought of as the purview of agencies responsible for science and/or environment, whereas food security research is usually thought of in terms of agriculture or aid agencies. Bringing these two groups together, and finding a common agenda which appeals to their respective governance and donor policies, is far from easy, especially as the funders and government structures that support the respective research communities are not traditional collaborators. An encouraging development is that the international development and national security communities are now interested in becoming involved in such research, although they have limited ability to fund research without an immediate agenda for action. Within the GEC community, the 'Global Change SysTem for Analysis, Research and Training' (START) and GECAFS have both had some success on this front, while the emerging CGIAR (Consultative Group on International Agricultural Research) agenda 'Climate Change, Agriculture and Food Security', has many aspects specifically designed to do this (CCAFS, 2009).

So who sets the GEC–food security research agenda, and how?

Given the points made above, the 'who' is ideally the regional stakeholder community at large (policy advisors/makers, resource managers, researchers, NGOs donors, etc.); and the 'how' is preferably by working interactively together, developing a shared vision and common understanding, and engendering trust. With such a broad stakeholder community this begs the question of how this engagement is managed, and by whom? Clearly it takes time, money and commitment, and may well result in an agenda that none of the participants anticipated. Further, the agenda-setting process needs to be flexible to inputs from science and policy developments as they emerge. This allows the agenda to encompass latest thinking, and also engenders the buy-in of a wider group (geographical and/or thematic) of stakeholders. There may also be a particular need to integrate the business sector and/or NGOs, and this particular dynamic is discussed in Box 4.

Some final points warrant stressing when designing and undertaking research which seeks to influence policy. It is crucial to establish the information needs of the policy process early in research planning, and to develop the research programme accordingly. Further aspects of particular relevance to the science-policy debate are the requirement to: (i) establish and maintain credibility with all stakeholders; (ii) achieve practicality; (iii) demonstrate usefulness to the designated beneficiaries; (iv) provide information to end-users in a timely and accessible format; and (v) ensure acceptability by end-users (Ingram et al., 2007a).

All these aspects will benefit from a carefully designed stakeholder engagement process which gives all stakeholders a sense of participation in, and joint-ownership of, the research process. Finally, and although a number of options have been presented above, it is important to appreciate that local customs and etiquette largely dictate the best way of establishing 'who needs to know what'. Local knowledge and people are critically important.

Box 4 Stakeholder dialogue involving the NGO and business communities.

Stakeholder dialogue can only thrive in an atmosphere of cooperation and mutual understanding, while serving the interests of the participants. There is always an aspect of power in dialogue. Certainly NGOs in stakeholder dialogue have to be able to exert such power in order to be taken seriously and to negotiate acceptable results. This power could be in the magnitude of their constituency, their high level relations, their press contacts or their cooperation with campaigning NGOs. NGOs are not, however, a monolithic entity. For example, 'watchdog' NGOs, of which Greenpeace is perhaps the most well-known example, focus on agenda-setting for public opinion and openly confront companies on their deemed bad behaviour. This is in contrast to 'dialogue' NGOs (e.g. World Wide Fund for Nature, WWF), which focus on cooperation with business and other stakeholders in common analysis and finding common solutions.

While companies may not fall into as many different categories as NGOs, there are clear differences within the business sector. Who is actually representing the company or a group of companies can have a strong bearing on what they are able to contribute to the dialogue and what subsequent actions they take. In general, public affairs managers are well trained in stakeholder dialogue, but can have problems with the acceptance of dialogue results within the company, while representatives from business interest organizations have the responsibility to also take care of the less innovative of their members. Research managers feel more comfortable with scientists than with NGO campaigners. All three kinds of professionals have their own multi-stakeholder networks. It is interesting to see that these groups of networks often have very limited overlap.

When to engage stakeholders in research planning

Stakeholder engagement is important throughout the GEC–food security research process, not only for setting agendas. This is because the roles of non-research stakeholders include (i) identifying the problem; (ii) helping to formulate the research agenda; (iii) being sources of information; (iv) being subjects of research; (v) being a target audience for dialogue on how to implement research results; (vi) implementing the research; and (vii) funding or co-sponsoring the research. Figure 2 gives a conceptual framework for organizing and understanding the complexity of stakeholder engagement organized around six interrelated science activities. These range from designing the research questions to communicating the message. All stakeholders are represented by one of the 'cards in the deck', and the three-dimensional depiction aims to capture the notion that multiple stakeholders can be involved at various points along the six research stages.

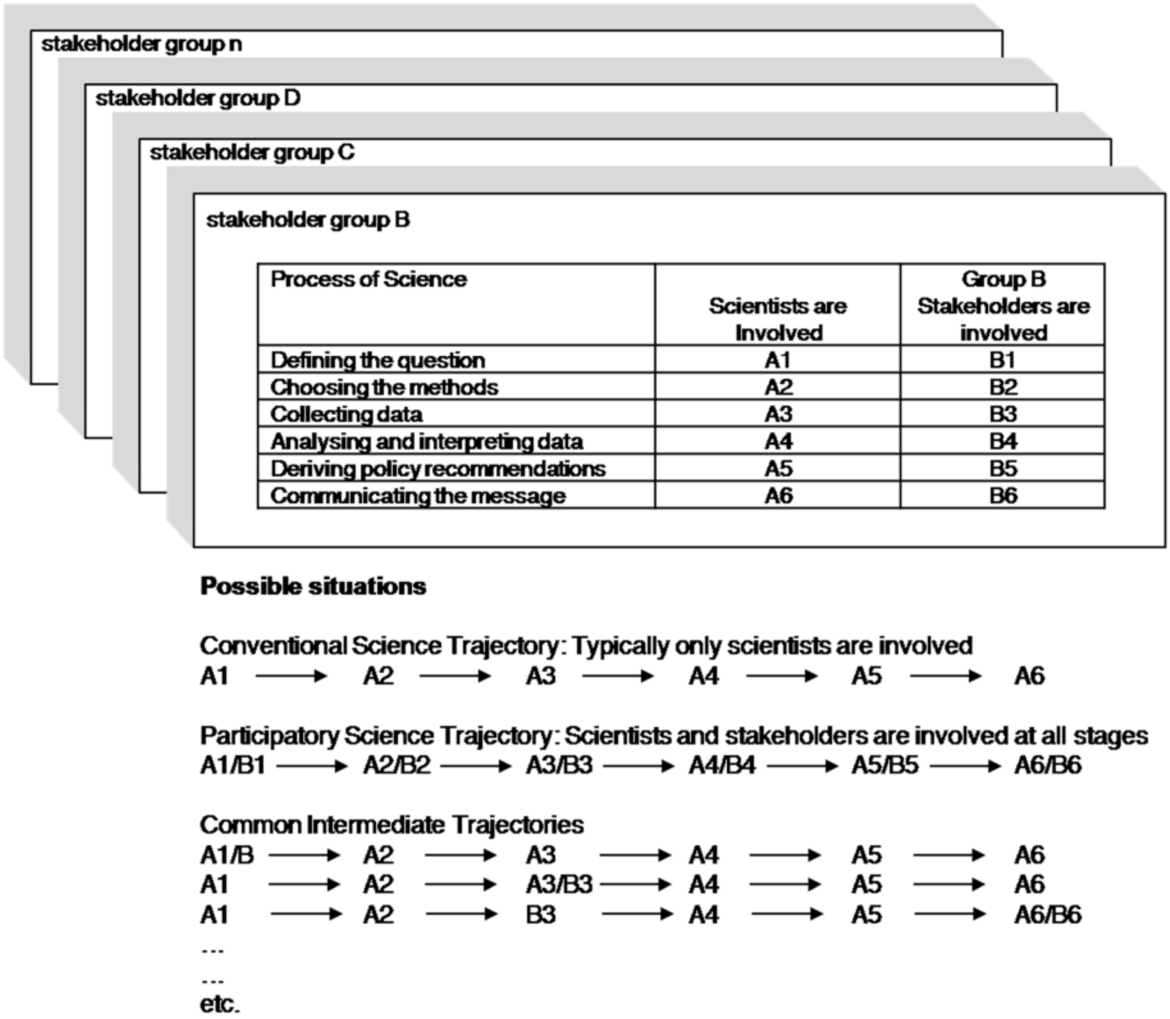

Figure 2: Organizing and understanding the complexity of stakeholder engagement, adapted from Brklacich et al. (2007)

While stakeholder engagement is important for research uptake, the timing, extent and nature of engagement depend on the precise situation, as illustrated by the Inter-American Institute for Global Change Research (IAI) Collaborative Research Network Program (CRN) case studies. These ranged from studies focused on a strictly defined scientific issue, initially involving only the GEC researchers, with stakeholder engagement coming later at the communication and dissemination stages. Other studies drew on a range of stakeholders from the outset. Across the range of IAI CRN case studies no single model emerged and no single reason or motivation-driving stakeholder participation was apparent. The following important points emerged from the IAI analysis (Brklacich et al., 2007):

- Stakeholders are heterogeneous groups representing multiple interests in GEC science.
- Stakeholders choose to participate in various stages of the scientific process, seldom participating in all.

- Stakeholders' participation in GEC science needs to be founded upon a mutual understanding of their contributions to the project and the benefits they will derive.
- Stakeholders make multiple contributions to GEC science, ranging from establishing the research agenda to participating in data collection to capacity building.
- Stakeholder participation in GEC science must be in accordance with international and national law as well as consistent with local norms for the sharing of knowledge and benefits.
- Stakeholder participation needs to be a planned set of activities within the GEC science process and be based upon an adaptive research design.
- GEC science must avoid overtaxing stakeholders and recognize that stakeholders have unequal capacities.
- The GEC science community has a responsibility to maintain and manage an environment that fosters long-term stakeholder participation.

As noted above, stakeholders choose to participate in various stages of the scientific process, but seldom participate in all. Brklacich et al. (2007) give an example of how planning agencies both helped define a river management study in the Amazon and also then helped communicate the project's findings. Increasingly, however, there is a view that the research process cannot meet stakeholder needs unless they, in fact, participate throughout the research process.

A particular example is the concept of co-production of knowledge, which is increasingly becoming a central feature of major research initiatives (e.g. UK's Living with Environmental Change programme; LWEC, 2009). An additional example is provided by the Famine Early Warning System (FEWS NET) project of the US Agency for International Development (USAID) (Box 5). A key insight to emerge from FEWS NET concerns the importance of engaging a range of stakeholders in order to achieve consensus at the research communication stage: once they agree to the nature and scope of the problem and come to the table to discuss what to do about it, they are able to determine what actions will help relieve the most intense symptoms of the food security crisis.

Box 5 Building consensus among stakeholders: A FEWS NET example.

USAID designed FEWS NET in 1986 to provide information on food security of communities in semi-arid regions so that widespread climate-related food security crises do not occur. FEWS NET includes stakeholders who work in the public, private or non-profit sectors in the region, and whose identities vary widely depending on the location. In some regions, the meteorological communities and health care workers are at the centre; in others it is nutrition experts from government and trade networks.

The primary objective of early warning systems is to elicit an appropriate response to an identified problem. Often, this requires that all stakeholders, from the various donors of food aid, regional organizations made up of numerous national governments, to national and local governance structures in the country in question, agree that there is a problem and understand and concur on its severity.

This consensus-building is very difficult and in many situations is often based on the quantitative remote sensing imagery that provides irrefutable evidence of a significant reduction in food production. Although everyone agrees that political and economic factors are usually far more important in determining food access and ultimately food security of a region, it is often the biophysical evidence that all parties can agree upon as being ‘real’, valid and conclusive. This puts remote sensing at centre stage in famine early warning systems, even in an era of widespread telecommunication systems that have greatly increased information availability from remote regions. Once stakeholders agree to the nature and scope of the problem and come to the table to discuss what to do about it, then they are able to address the underlying political and economic causes of the problem through efforts to engage partners to provide income support, clean drinking water, health interventions and other responses appropriate to the situation in addition to food aid.

As stakeholders continue to increase their attention and focus on food security issues outside of food availability, the pressure will grow to transform the food aid system to provide information on the wider food system’s functioning during a crisis (Okali et al., 1994; Haggar et al., 2001; Brown, 2008).

How to engage stakeholders in research planning

As noted above, stakeholder engagement is of great importance in the research design phase and a combination of approaches (consultancies, agenda-setting workshops and informal approaches) can be employed to help set the agenda. Each of these is discussed below.

Consultancies. Consultancies, where researchers are hired to ascertain stakeholder views, prove particularly effective in determining information need from stakeholders who would not normally participate in, or feel comfortable at, an ‘academic’ brainstorming workshop. Examples of stakeholders who would be consulted for regional-level input include senior policy advisors from intergovernmental organizations or regional bodies (e.g. Southern Africa Development Community, SADC; European Commission), resource managers (e.g. operations managers of major/trans-boundary irrigation schemes), and representatives from specific target groups (e.g. farmer associations or major supermarkets). Careful selection of consultants is important: local researchers who are experienced in stakeholder dialogue (rather than international experts) usually have the best feel for the nature of the issues at regional level, and generally have the best contacts (sometimes personal, sometimes professional) and hence access to interviewees. A small team might be needed to collectively cover the main science areas. A ‘down side’ of this process is that interviewees may not strongly feel part of a collective agenda-setting exercise, and do not benefit from discussion with others in a workshop setting.

Agenda-setting workshops. These bring the researchers together with the various stakeholders and are commonly used in designing research projects. They have the advantage of sharing information more openly. Workshop outputs can be seen to be a product of collective discussion and consensus (as opposed to consultancies) and hence can have more ‘standing’. This can be very important both scientifically and politically, especially if a multi-country, multi-disciplinary project is being planned. They can, however, be expensive in cash terms (especially if long-distance travel is involved), and also in time and effort in design, running and reporting. It may also be difficult to elicit attendance from senior stakeholders, such as senior government officials. There is also a risk that such workshops come up with rather long ‘shopping lists’ of research needs that are expressed too generally to provide the sharp focus that is needed on the key policy issues. Clear workshop objectives and skilful facilitation can overcome this potential problem.

Informal approaches. Informal approaches by researchers to other stakeholders can play a very important role in clarifying particular issues and helping to achieve ‘buy-in’ of key people. Important messages can often be better relayed outside the formal environment of a workshop session or interview. Workshop ‘socials’ and field trips are excellent opportunities for informal exchange, and a relaxed evening together can be very helpful in helping people to get to know each other better.

It was clear from GECAFS planning exercises that neither consultancies nor workshops alone delivered a clear research agenda and that some follow-up activities (such as sending drafts to technical advisors in regional agencies for their comments) were needed in all the GECAFS regional projects. Although more protracted than would normally be the case for a disciplinary science planning exercise, this process in itself had three important spin-offs: (i) it helped raise awareness of the GEC issues within the policy and other stakeholder communities; (ii) it helped raise awareness of the policy and resource management issues within the GEC science community; and (iii) it identified, and began to build, a cohort of stakeholders keen to work collaboratively.

Involving stakeholders in research planning can reveal issues that would be missed by a science-alone process. A good example emerged in GECAFS early planning discussions with senior policy-makers in the Indo-Gangetic Plains. There is a policy imperative to address the massive seasonal movement of casual labour from east to west, which brings considerable social upheaval. Hence, addressing labour issues was called for as a component of the GEC–food security agenda for the region, and research questions were developed accordingly (GECAFS, 2008). This dialogue identified a key policy problem that needed immediate solutions, along with the more general concerns about medium- to long-term GEC–food security issues. It challenged the GEC research community to incorporate issues of which they were hitherto ignorant, thereby developing an agenda of greater interest and relevance to policy imperatives. In so doing, it considerably increased the need for a larger number of disciplines to be engaged but this in turn led to greater networking.

Elements of good practice in stakeholder engagement

A number of recent studies have identified problems experienced in the management and communication of research to inform policy-making and regulation (see, for example Holmes and Clark, 2008; Holmes and Savgard, 2008; Bielak et al., 2009). These studies have also identified elements of good practice in respect of the planning and execution of research, the communication of results and the evaluation of uptake and impact which are now discussed briefly. In addition, the Overseas Development Institution's 'Research and Policy in Development Programme' (RAPID) has published a wide range of practical frameworks and tools for researchers, policy-makers and intermediary organizations, which are targeted at developing countries (ODI, 2009).

Given the importance of research influence on policy for actually making change happen, how can research-policy interactions best be enhanced? Bammer (Bammer, 2008a; Bammer et al., 2010) presents six checklists which illustrate complementary facets of this complex process:

1. Barriers to cooperation between policy-makers and researchers (Gregrich, 2003);
2. Different emphases of policy-makers and researchers (Heyman, 2000);
3. 'Irrefutability' of the evidence versus the 'immutability' of policy (Gibson, 2003b);
4. Five indicators of policy-maker responsiveness to research (Gibson, 2003a);
5. Questions for researchers to think strategically about their interactions with policy-makers (Jones and Seelig, 2004);
6. Questions and suggestions for researchers on how to influence policy and practice (Court and Young, 2006; and see Table 1, slightly modified from the original).

<Table 1 placed at end of paper >

As highlighted above, research is more likely to be successful in informing regional policy-making or regulation if it involves the decision-makers mandated to work at this spatial level (and/or their advisors) in the *planning* stages of research projects and programmes. Where the nature of the issue requires it (contested issues, complex systems and uncertain science as discussed above) a broader range of stakeholders should be involved. Each player may see the issue differently, reflecting what might well be their different 'world views': researchers through their disciplinary lenses; policy-makers and regulators as conditioned by the constraints and pressures they are working to; and other stakeholders influenced by their particular concerns and experiences of the issue.

If the answers generated by the research are to be meaningful to these different players, a framing of the research question needs to be arrived at through discussion that reflects their various viewpoints. Framing issues and consequent research questions based on this is inevitably selective, and hence it is important to engage with as many different kinds of problem formulation as possible (Becker, 2003; Shove, 2006).

It is important too that these interactions are sustained through the conduct of the research. If not, then as the questions faced by regional policy-makers evolve, and the research path develops according to the practicalities and consequences of discovery, the questions and the answers may drift apart. If well managed, researchers, policy-makers and other stakeholders will share ownership of the resulting knowledge and system understanding, which will improve the chances that consequent decisions are widely supported.

With regard to *communicating* the findings of research, the approach needs to use a set of communication forms and channels tailored to the audience and the circumstances. Communication through written media should be complemented with face-to-face interaction between researchers and stakeholders, allowing confidence in results to be tested and implications for decision-making to be explored.

The communication strategy needs to be well thought through and planned in advance, and a view developed on the intended impact of the communication. However, the context for communication can change quickly: it is important to anticipate changes where possible and to respond flexibly. Wherever possible, good relationships and understanding between research and user communities should be developed as a helpful precursor to research dissemination. As an example, a high-level briefing to policy-makers, funders and senior scientists from the Indo-Gangetic Plain organized to present GECAFS research findings was the more valuable as the good working relationships developed over the project life facilitated a full and frank discussion on the value of the research.

Increasingly, the benefits of, and necessity for, two-way communication with a broad range of stakeholders is recognized. In part, this reflects a shift from a top-down, directive approach to securing societal change to one which centres on encouraging shifts in behaviour of the many individual agents who collectively can achieve the desired outcome.

A further dimension of good practice concerns the characteristics of ‘robust’ evidence. Clark et al. (2002) consider how institutions mediate the impacts of scientific assessments on global environmental affairs and conclude that the most influential assessments are those that are perceived by a broad range of actors as having three attributes:

- *salience:* whether an actor perceives the assessment to be addressing questions relevant to their policy or behavioural choices;
- *credibility:* whether an actor perceives the assessment’s arguments to meet standards of scientific plausibility and technical adequacy; and
- *legitimacy:* whether an actor perceives the assessment as unbiased and meeting standards of political fairness.

An additional point, and one that been particularly important in relation to the recent ‘climate-gate’ issue, concerns *transparency*: whether the research process is seen as sufficiently open.

Finally, it is worth noting that for stakeholder engagement to be effective, the personalities of all those involved are important; human nature can frustrate earnest attempts to communicate genially and find consensus. It is crucial not to 'get off on the wrong foot' so some knowledge of the proposed participants' personalities is important, especially when facilitating first-time interactions. Similarly, knowledge of any 'history' of prior interactions between stakeholders (be it good or bad) can be very helpful in designing meetings and other interactions. Setting the right atmosphere for the meeting is also important and a range of informal and/or social activities can be a key aspect for building trust and developing friendships. These aspects not only help with the meeting itself, but can also develop a strong foundation for longer-term collaborations.

Interactions with stakeholders to enhance decision support for food security

The policy community is often the main stakeholder group of interest to researchers working at the regional level. To be of use in supporting policy formulation, research on the development and assessment of possible strategies to adapt food systems to the impacts of GEC should be elaborated in the context of the policy process. As the food security–GEC debate encompasses many complex and interactive issues, a structured dialogue is needed to assist the collaboration among scientists and policy-makers. This can be facilitated by a variety of decision support approaches and tools, ranging from general discussions and mutual awareness-raising (including formal joint exercises such as scenario construction and analyses; see Box 6) to simulation modelling, geographic information systems and other tools for conducting quantitative analyses of trade-offs of given policy options.

Box 6 Using scenario exercises to facilitate communication among stakeholders.

Scenario exercises can facilitate stakeholder involvement, thus linking research activities more closely to actual decision processes. This can be especially effective where dialogue is centred on uncertainties and complexity, and an assessment of future trends is sought – as is the case when discussing GEC interactions with medium- to long-term implications for food security. Scenario exercises have shown considerable potential to provide a mechanism for involving a range of stakeholders and for facilitating communication between them. Generally speaking, scenario exercises can be and have been effective in supporting three main clusters in any assessment (Henrichs et al., 2010):

1. The research and scientific exploration cluster (i.e. helping to better understand the dynamics of (complex) systems by exploring the interaction between key drivers).
2. The education and public information cluster (i.e. providing a space for structuring, conveying and illustrating different perceptions about unfolding and future trends).
3. The decision-support and strategic planning cluster (i.e. offering a platform for soliciting views about expected future developments and to analyse trade-offs between pathways).

Ideally, a scenario exercise contributes – to some degree – to all of the above by aiming to enhance *credibility* through expert knowledge (i.e. 'Is the exercise convincing?'), *salience* to stakeholders (i.e.

‘Is the exercise relevant?’), and *legitimacy* in the way stakeholders are involved (i.e. ‘Is the exercise inclusive and unbiased?’); also see Alcamo and Henrichs (2008). All three aspects have direct relevance to facilitating communication with and between stakeholders.

It is worthwhile noting that the discussions by which scenarios are developed (i.e. the ‘process’) can be as least as important as the scenarios themselves (i.e. the ‘product’), because they allow uncertainties to be discussed by a range of stakeholders – see Biggs et al. (2004) or Henrichs et al. (2010).

Three process-related benefits particularly contribute to this (following Okali et al., 1994; Haggar et al., 2001; Henrichs et al., 2010):

1. Those who participate in a scenario development process gain better understanding of the issue via the structured dialogue between experts and stakeholders.
2. Scenario exercises offer a ‘neutral space’ to discuss future challenges as uncertainty about the future has an ‘equalizing effect’: as no-one can predict the future, thus no-one is ‘right’. This opportunity for open discussion also helps in engendering mutual respect, understanding and trust, which crucial for building effective research teams for follow-up activities.
3. The discussion of, and reflection on, possible future trends can create the ground to reveal conflicts, common views about goals, or different perceptions about the today’s challenges.

A scenario exercise was conducted as part of the GECAFS research on GEC and food security in the Caribbean. The exercise’s aim was twofold. First, it set out to develop a set of prototype Caribbean scenarios for research on GEC and regional food systems (i.e. develop a ‘product’; as published in GECAFS, 2006b). Second, the exercise aimed to initiate and facilitate an enhanced dialogue between stakeholders, including researchers and policy-makers from different countries in the region and regional bodies, on the issue of regional food security (i.e. facilitate a ‘process’; see GECAFS (2006b), for more details). The enhanced communication and team-building engendered by the scenario process resulted in continued interaction between the stakeholders beyond the scenario exercise itself.

Application of a holistic decision support process raises awareness in the policy community of the interactions between GEC and food systems; identifies and communicates the options and constraints facing researchers and policy-makers; identifies methods and tools that best facilitate the dialogue between scientists and policy-makers related to GEC and food systems; and helps both researchers and policy-makers assess the viability of different technical and policy adaptation strategies by analysing their potential consequences (feed-backs) for food security and environmental goals.

But how can decision support best be delivered? Research on improved decision support needs to bring together a number of different approaches: ‘integration and implementation sciences’ to draw together and strengthen the theory and methods necessary to tackle complex societal issues (Bammer, 2005); research on how an adaptive management ethic and practice that supports the concept of sustainable development can be initiated and implemented in complex, regional or large-scale contexts (Allen, 2001); and the adaptive management approach for incorporating communications, analysis and scenarios development (Lee, 1999; Gunderson and Holling, 2002; Henrichs, 2006). Such approaches lay the foundations for delivering specific support for key policy-makers at the national and regional levels (as outlined by Lal et al., 2001). These approaches rely upon a strategy that begins with identifying the key stakeholders, includes a process of reflection to develop a common understanding of the problem, and then proceeds through a joint learning process. But, and as noted above, designing such a strategy – let alone implementing it – is far from straightforward. A greater appreciation of such ideals will however help researchers and policy-makers work together so that the best available scientific information informs the policy process. Another way to think of decision support platforms is that they include a set of tools, methods and information that facilitates the dialogue among scientists and policy-makers in a co-learning framework. This co-learning approach is central to the engagement and decision support process. Furthermore, this approach provides a strong basis for social, biophysical and economic scientists to learn how to effectively address complex issues in a holistic, practical setting.

Innovative decision support platforms (such as the 'Questions and Decisions' (QnD) system: Kiker et al., 2005; Kiker and Linkov, 2006) will be needed for food security–GEC research as they allow the incorporation of complex ecosystem models, and their linkage to environmental-based decision support tools, in a systematic way. Other researchers have placed particular emphasis on trade-off analysis, integrating biophysical and socio-economic models in a process or dialogue with policy-makers (Antle et al., 2003; Stoorvogel et al., 2004). Antle (2003) emphasizes that the approach is a ‘process’, not a model per se. The form of the model and analyses are guided through stakeholder dialogue, thereby helping regional policy-makers and other stakeholders to understand and plan for impacts of GEC in the social, political and economic context in which decisions are made and policies are implemented. Decision support platforms will be used within a decision support process that combines data processing and analysis, modelling, evaluation and assessment tools, enhanced concepts (e.g. vulnerability) and policy projections (national, regional and international). The decision support process will also use a range of dissemination mechanisms (e.g. policy briefs, printed maps). No single decision support system will fit the needs of all situations, so a flexible framework will be needed. The aim of the GECAFS decision support research has been to develop approaches that will help policy-makers and other stakeholders in clear and effective ways. The scenarios exercises were very effective components in this regard, primarily by facilitating communication and mutual understanding of the range of stakeholders’ world views.

Figure 3 shows how the various components of food systems research (i.e. on food systems and their vulnerability to GEC; adaptation options; scenario construction; and trade-off analyses) can be brought together in a structured dialogue between scientists and stakeholders. It also shows the critical aspect of joint agenda-setting.

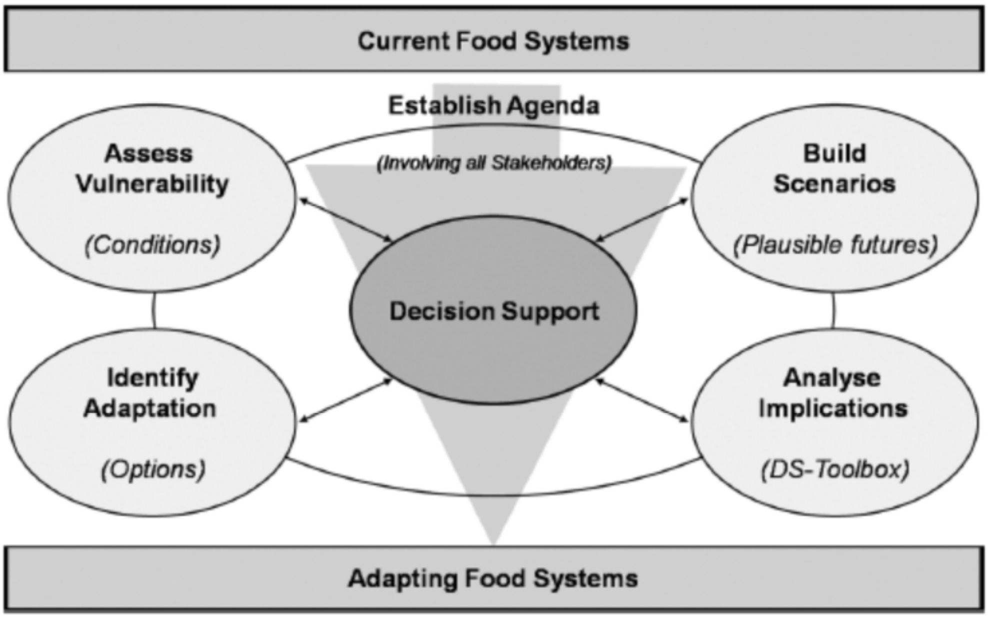

Figure 3 The various components of GECAFS research are brought together in a structured dialogue between scientists, policy-makers and other stakeholders (adapted from Henrichs, 2006).

Assessing effectiveness of stakeholder engagement

While enhanced stakeholder engagement might be high on the researchers' agendas, and considerable efforts are made to develop links, it is important to assess its effectiveness. Ultimately, of course, the intention of research in the GEC/food security area is to bring about a change in behaviour of the intended beneficiaries so that the outcomes of their actions becomes more effective in combating food insecurity – the research 'impact' (CCAFS, 2009). This can take many years to be firmly seen, and can be hard to measure, not least because of other 'confounding factors' that will influence the eventual impact of any policy. Hence, it is appropriate to examine intermediate measures of uptake and impact which can be evaluated on a shorter timeframe, are more directly determined by the research project and which can provide an early indication as to the likelihood of the eventual outcome.

It is meanwhile possible to estimate the effectiveness of stakeholder engagement by undertaking a survey of stakeholders' views vis-à-vis the researchers' aspirations. Survey results can be very revealing and help set priorities for both follow-up studies and enhanced stakeholder engagement. Box 7 summarizes some of the questions and responses from a survey of GECAFS stakeholders.

Box 7 The GECAFS stakeholder survey.

After about five years of project activities, GECAFS designed and conducted an email survey intended to assess the effectiveness of reaching out to a broad user community (i.e. stakeholders), and also to gather feedback on ways in which to better serve their needs in future.

Questions covered a range of aspects including the nature of respondents' interactions with GECAFS such as: *Does/did your engagement contribute positively to your work? Are there any specific forms of interaction that you have had with GECAFS that you found particularly useful for your work? Can you suggest any ways in which GECAFS can contribute more substantially to your work?* And more general issues such as*: Who, in your opinion, should GECAFS seek to influence with its research work and findings? Can you suggest ways in which GECAFS can strengthen its presence among national and regional stakeholders in your region? To what extent, in your opinion, does GECAFS contribute to making linkages between science and policy-making? Can you suggest any ways in which to strengthen this contribution?*

Other questions cover a range of issues such as the nature and format of GECAFS workshops, the website, and the desirability of a newsletter. Feedback was received from about 30 of the ca. 100 recipients.

Almost all the participants in the survey felt that their interaction with GECAFS had contributed positively to their work in concrete ways, and many were able to cite specific examples ('*it expanded my interaction outside the notion of climate change and agricultural production to a food system as defined by GECAFS*').

Most respondents felt workshops and meetings were the most beneficial form of interaction they had with GECAFS in the past, allowing for a better understanding of GECAFS concepts, as well as presenting an opportunity for interaction with policy-makers and for networking ('*allowed interaction with some of the finest scientists in vulnerability science, environmental economist, agricultural production etc*.').

In specific relation to stakeholder engagement, most of the respondents felt that GECAFS' key target groups should be policy and decision-making communities at the global, regional and national levels, and the science community. Policy-makers specifically identified include politicians, Permanent Secretaries, Chief Technical Officers in ministries responsible for fisheries, agriculture, environment, industry and finance, and fisher folk leaders, agriculture department officials and opinion leaders in rural communities. In addition to the policy and science communities, other target groups identified by the respondents include donors; relevant practitioners and stakeholders including representatives of agro-business, farmers, food consumers, producers and traders; international agencies such as FAO (United Nations Food and Agricultural Organization) and CGIAR; universities (researchers and students); media; NGOs; and relevant research and development institutions.

Several respondents felt, however, that GECAFS outreach to these communities was limited. Some cited possible reasons for this – including the need to have something substantial to offer before committing too much time to outreach, in terms of both findings and resources for further research; the need for funding to carry out work at the regional and national levels, as it is difficult to reach out to politicians and other decision-makers without concrete results; and the difficulties in engaging communities (such as policy-makers) whose timescales are generally more immediate than those of the research community.

Specific methods and tools suggested by the survey respondents to improve GECAFS' outreach and stakeholder interaction included:

- Identify and stick to a few themes.
- Involve stakeholders in designing research projects to create ownership of results.
- Develop smaller, more marketable projects for donor funding and greater stakeholder participation.
- Develop simulation models on food security and its socioeconomic impacts.
- Work with collaborative institutes (like CARDI) who work directly with policy-makers.
- Become a strong player in the work of the European Science Foundation.
- Develop a research programme with the CGIAR.
- Determine who the real decision-makers are in government – those who advise the policy level.
- Piggyback with relevant regional outreach activities.
- Organize regional workshops using research and papers already developed, with decision and policy-makers in attendance.

Finally, the following questions serve as a checklist to help researchers undertake an *ex post* analysis of their interactions with the regional policy process (adapted from Bammer, 2008b):

- What was the purpose of providing research support to policy and who was intended to benefit?
- What parts of the policy system were targeted and what research was relevant?
- Who provided the research support and how did they do it?
- What contextual (i.e. broader external context) factors were important in getting the research recognized or legitimated?
- What was the outcome?

Conclusions

The ultimate aim of many GEC–food security research projects is to help people adapt to the additional problems GEC will bring to achieving food security – which is, for many, already a complex challenge. For instance, the stated goal of the GECAFS project was drafted as 'To determine strategies to cope with the impacts of global environmental change on food systems and to assess the environmental and socioeconomic consequences of adaptive responses aimed at improving food security'. 'Determining strategies' involves more than producing science outputs – it requires very active engagement with stakeholders to discuss viability – an unviable plan (albeit scientifically robust) is not a particularly valuable strategy! So, in order to achieve ambitious goals of this nature it can be helpful to clearly differentiate between research *outputs*, research *outcomes* and research *impacts*. This helps ‘break down’ what might be a high-level project objective into more manageable components and clarifies the comparative roles the different stakeholders play in each.

Coping and adaptation means ‘doing things differently’ (i.e. changing behaviours). Real research impact will only come about if intended beneficiaries can see the benefits of making such changes, which will be most likely if they understand and trust the research process – and this will most likely be the case if stakeholder engagement is a fundamental aspect of research. This is especially important in agenda-setting and the number of different approaches discussed above (formal agenda-setting workshops, consultancies and informal approaches) can be useful. Different combinations of these approaches, or even all three, help in establishing ‘buy-in’ to the research process by a wider range of stakeholders than just researchers. Choosing the best approach(es), and deciding when and where implementation would be most effective, is a crucial part of research planning, and stakeholder engagement at the regional level.

Table 1 *A framework of questions and suggestions for researchers aiming to influence policy (adapted from Court and Young, 2006)*

	What you need to know	**What you need to do**	**How to do it**
Political context	Who are the policy-makers? Is there policy-maker demand for new ideas? What are the sources/strengths of resistance? What is the policy-making process? What are the opportunities and timing for input into formal processes?	Get to know the policy-makers, their agendas and their constraints. Identify potential supporters and opponents. Keep an eye on the horizon and prepare for opportunities in regular policy processes. Look out for – and react to – unexpected policy 'windows'.	Work with the policy-makers. Seek commissions. Line up research programs with high profile policy events. Reserve resources to be able to move quickly to respond to policy windows. Allow sufficient time and resources.
Evidence	What is the current theory? What are the prevailing narratives? How divergent is the new evidence? What sort of evidence will convince policy-makers?	Establish credibility over the long term. Provide practical solutions to problems. Establish legitimacy. Build a convincing case and present clear policy options. Package new ideas in familiar theory or narratives. Communicate effectively.	Build up programs of high-quality work. Action-research and pilot projects to demonstrate benefits of new approaches. Use participatory approaches to help with legitimacy and implementation. Clear strategy and resources for communication from start. Face-to-face communication.
Links	Who are the key stakeholders in the policy discourse? What links and networks exist between them? Who are the intermediaries and what influence do they have? Whose side are they on?	Get to know the other stakeholders. Establish a presence in existing networks. Build coalitions with like-minded stakeholders. Build new policy networks.	Partnerships between researchers, policy-makers, and communities. Identify key networkers and salespeople. Use informal contacts.
External influences	Who are main national and international actors in the policy process? What influence do they have? What are their action priorities? What are their research priorities and mechanisms? How do they implement policy?	Get to know the main actors, their priorities and constraints. Identify potential supporters, key individuals, and networks. Establish credibility. Keep an eye on policies of the main actors and look out for policy windows.	Develop extensive background on main actor policies. Orient communications to suit main actor priorities and language. Try to work with the main actors and seek commissions. Contact (regularly) key individuals.

Paper 6: Undertaking Research at the Regional Level

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Ingram, JSI and A-M Izac. 2010. Undertaking research at the regional level. pp 221-240 In: *Food Security and Global Environmental Change*. JSI Ingram, PJ Ericksen and DM Liverman (Eds). Earthscan, London.

Introduction

The rationale for, and benefits to be gained from, undertaking global environmental change (GEC)/food security research at regional level are discussed in Liverman and Ingram (2010: Paper 4). However, given the varied and complex interactions between regional and national objectives, research at the regional level has to encompass considerations of multilevel dynamics. Further, many of the food security issues are based on socio-ecological interactions that need to be studied at a number of scales and levels. This gives rise to three types of research questions that all need to be addressed to recognize the complex spatial and temporal dynamics within a region and to cover the varied interests of regional-level stakeholders:

- *Regional-level questions*, to address issues relating to the region as a whole that cut across the range of different conditions within the region. Example: What regional-level policy instruments and strategies would reduce GEC threats to regional food security? (e.g. transboundary water agreements; intraregional trade; strategic food banks; reduction of non-tariff barriers; regional disaster management; regional licensing for agricultural inputs such as agrochemicals and genetically modified organisms (GMOs), regionally coordinated taxation and export policies).

- *Subregional-level questions,* which are researched in a set of case studies selected to represent – as best as possible – the heterogeneity of a range of parameters across the region. These case studies could be a district or even a (small) country. Example: What aspects of local governance affect the development and implementation of food system adaptation options and strategies? (e.g. vision, popular acceptance, corruption, accountability and social auditing, capacity and capability, price stability, food standards).

- *Cross-level questions*. Example: What are the key interactions between policy instruments, strategies and interventions set at different levels? (e.g. national insurance policy and regional fisheries production; land-use regulation and local disaster management; local distribution infrastructure and intra-regional trade agreements; crop diversification and intra-regional trade; regional vs. local early warning systems).

Of the three types of questions, the subregional level and single cropping season is perhaps the best researched to date, and especially the biophysical aspects of food production. However, in terms of food security, understanding and managing the dynamic cross-level issues along all relevant scales are arguably more important. This certainly requires an interdisciplinary approach, although research on cross-level interactions along jurisdictional and institutional scales is perhaps of more interest to social scientists. This dichotomy is especially so for regional/subregional cases where mismatch between regional and national policies can severely compromise the effectiveness of food production and other key factors determining food security. Despite the multiscale, multilevel nature of food systems, different scales are usually singled out as important at different levels, and which might act as bottlenecks to cross-level interactions.

Matching research to regional information needs: Who is the 'client'?

Several arguments in support of undertaking GEC/food security research at regional level have been presented in Liverman and Ingram (2010: Paper 4). The notion of regional research does however raise two important questions: 'Who in particular wants to use research results at this spatial resolution?'; and 'What do they want to know?'. While there might well be academic interest in such studies, their utility in assisting in policy formulation at the regional level and their relevance to regional resource management would be slight if there is no obvious 'client'. Further, even if identified, these clients need to be engaged in helping to set the appropriate research agenda; it is important that research outputs match the information needs in relation to managing common agro-ecological zones, shared river basins, common problems, etc. Identifying groups and agencies that need information at these spatial levels helps to determine the 'client'.

Identifying the 'client' at regional level can be relatively easy if, by chance, there is a formal entity whose geographical mandate approximately matches the geographical area of interest from a GEC viewpoint. Often such entities are economic and/or political groupings, such as the Caribbean Community (CARICOM, which includes many of the Caribbean nations) and which nests well with regional studies of GEC-induced changes in hurricane track and intensity; or the South Asian Association for Regional Cooperation (SAARC) with reference to Asian 'brown cloud' studies. Another good example can be found in Southern Africa, where subcontinental studies on, for example, the regional transport of air, human vulnerability and biodiversity loss, match much of the Southern Africa Development Community (SADC) region. While many such bodies have a clear food security mandate, and there may be a clearly expressed need for GEC/food security research for a given region and/or by a given body, translating this into a practical research package is daunting.

One of the first challenges is to establish with which individual(s) in such organizations to engage. Often there is a unit related to food security (e.g. in SADC there is the Directorate for Food, Agriculture and Natural Resources, FANR). But given the major dependence on agriculture in many parts of the world, coupled with what might be chronic (or worse, acute) food insecurity, staff in such units are often overstretched and under resourced. Despite the agreed need (and usually sincere desire) to engage in planning discussions and follow-up activities, there is simply insufficient human capacity to do so; staff often need to respond to immediate crises (e.g. a deepening drought, or an imminent hurricane) rather than concentrate on more strategic planning issues. Holding planning meetings in locations where representatives from such bodies would most likely be able to participate (e.g. for southern Africa in Gaborone, where SADC-FANR is based) can help gain input, and hence an insight, into policy interests. An innovation developed by the International Food Policy Research Institute's (IFPRI) RENEWAL project has been the establishment of Advisory Panels to ensure 'in-reach'. This model involves explicitly including policy-makers and other stakeholders in the research from inception, ensuring that the project 'asked the right questions' that were relevant and important. These panels were established in the main countries in which RENEWAL operates. Although an attempt was made to set up a similar structure at regional level, it became evident that staff of relevant directorates (especially FANR) are heavily overstretched and the effectiveness of this was questionable.

Despite the number of examples discussed above, it is questionable whether these tactical approaches really add up to a strategic decision at a political level to engage in systematic analysis and preparedness for GEC/food security issues. An education/capacity-building effort at a political and decision-making level that involves the food industry and other stakeholders appears to also be needed. It is important to realize, however, that regional bodies such as EU or CARICOM comprise member states, each of which has its own national concerns and goals. What might appear a logical way forward for the region as a whole might be thwarted by political and economic concerns of individual members, or by conflicts between them, such as between India and Pakistan. For instance, since the 1980s, SADC has been considering the establishment of a strategic food reserve to deal with the growing frequency of natural disasters. Early proposals were based on considerations of enough physical maize stock for 12 months' consumption. Despite this, most government reserves were at record low stocks at the 2002/3 marketing year (Mano et al., 2003; Kurukulasuriya et al., 2006). This regional/national dynamic adds a further complication to identifying the regional 'client'.

Methods to engender research at regional level

Within a given region there are often many research projects working at the national or sub-national level addressing aspects of GEC and food system research (e.g. social, agronomic, fisheries, policy, economics, ecological and climate sciences). If integrated, these individual projects could be very relevant both to the broader, interdisciplinary GEC/food security agenda and to higher-level analyses of value to policy development at the regional level. Such integration depends on effective networking.

Analysis of a number of international projects has identified good examples of how to engender such networks, the importance of team-building and standardized methods, the value of using integrated scenario approaches for facilitating regional-level analyses, possible ways to overcome some of the many methodological challenges for research at regional level, identifying case study sites and the value of linking regional research within the broader international context. These are discussed below.

Encouraging regional research networks

The Assessments of Impacts and Adaptations to Climate Change project (AIACC) focussed on training and mentoring developing country scientists to undertake multi-sector, multi-country research. This addressed a range of questions about vulnerabilities to climate change and multiple other stresses, their implications for human development, and policy options for responding and the information, knowledge, tools and skills produced by AIACC research enhanced the ability of developing countries to assess their vulnerabilities and adaptation options. A key aspect of AIACC was the development of regional research networks and to this end AIACC was structured in such a way as to encourage interactions across research disciplines, institutions, and political boundaries, and enable more effective south–south exchange of information, knowledge and capacity, and through that process engender network building. This approach, replicated across such a large number of assessments and in contrasting research environments, generated a number of key insights that can inform 'good practice' recommendations for encouraging regional research networks. These include the need to consider broad criteria in selecting research and assessment teams; the value of coordinating multiple climate change assessments under the umbrella of a larger project; the value of providing flexible, bottom-up management; and the need to promote multiple, reinforcing activities for capacity-building (Box 1).

Box 1 Recommendations from the AIACC project for encouraging regional research networks.

The Assessments of Impacts and Adaptations to Climate Change project (AIACC) was a global initiative developed in collaboration with the United Nations Environment Programme (UNEP)/World Meteorological Organization (WMO) Intergovernmental Panel on Climate Change (IPCC) and funded by the Global Environment Facility to advance scientific understanding of climate change vulnerabilities and adaptation options in developing countries. It was completed in 2007.

Key lessons from the AIACC project on simultaneously achieving regional network building and capacity development included the following:

- *Consider broad criteria in selecting research and assessment teams.* The peer-review process of selecting proposals for the AIACC project considered the need for representation of countries with low capacity as a co-criterion to scientific merit. This inclusive selection approach helped to broaden the reach to least developed countries where there are substantial knowledge and capacity gaps. The presence of a strong technical support team within the project and the project's emphasis on capacity-building helped to support the needs of teams from low capacity countries.

- *Coordinate assessments*. Execution of multiple climate change assessments under the umbrella of a larger project produced synergistic benefits. The AIACC project provided numerous opportunities for the different teams to interact with each other through regional workshops, synthesis activities, joint training activities, peer-review of each other's work, and electronic communication. Moreover, executing a group of assessments together also made it possible for investigators from multiple projects of similar design to compare results from across the projects and to identify and synthesize common lessons.
- *Provide for flexible, bottom-up management.* The teams were given wide latitude to set their specific objectives, focus on sectors and issues of their choosing and select the methods and tools to be applied. This allowed for a high degree of innovation and matching of the focus and design of each assessment to the priorities, capabilities and interests of the teams, and it allowed for flexibility in adapted to shifting priorities within the assessment. The flexible and 'bottom-up' approach to project management created good working relationships and respect among the participating institutions and was a key factor in the overall performance of the project.
- *Promote multiple, reinforcing activities for capacity-building*. A comprehensive programme of learning-by-doing, technical assistance, group training, self-designed training and networking was demonstrated to be effective at building capacity. Efforts were made to utilize the expertise of developing country participants to assist with training and capacity transfers to their colleagues. This worked well and even led to a number of training workshops organized by some of the teams for colleagues in other projects. A substantial portion of the capacity-building resulted from the cross-project learning and sharing of methods, expertise, data and experiences. The central role assumed by regionally based capacity-building and regional research networks helped to ensure greater sustainability and achieve a wider impact than is generally the case with north–south transfers of expertise and capacity development.

The importance of team-building and standardised methods

The breadth and complexity of GEC/food security research at regional level necessitates bringing together a group of researchers (with varied skills) and other stakeholders. Such groups can develop into strong research networks but this depends on careful team-building. This was particularly important in the Alternatives to Slash-and-Burn Program (ASB, see Box 2).

Box 2 Alternatives to Slash-and-Burn (ASB) Program.

A multi-institutional and global research programme launched in 1993, the *ASB Program*, provides a successful example of a global programme which has regional sites in three continents. ASB has been focusing on tropical forest margins to develop more environment-friendly farming techniques that would result in local and regional food security and on slowing deforestation at forest margins. It has now grown to a global partnership of over 80 institutions, conducting research in 12 tropical forest biomes (or biologically diverse areas) in the Amazon, Congo basin, northern Thailand, and the islands of Mindanao in Philippines and Sumatra in Indonesia. Its efforts are directed toward curbing deforestation while ensuring that those living in poverty benefit from nature's environmental services and achieve food security.

A partnership of institutions around the world, including research institutes, non-governmental organizations, universities, community organizations, and farmers' groups, ASB operates as a multidisciplinary consortium for research, development and capacity-building. ASB applies an integrated natural resource management (iNRM) approach to analysis and action (Izac and Sanchez, 2001) through long-term engagement with local communities and policy-makers.

ASB undertakes participatory research and development of technological, institutional and policy innovations to raise productivity and income of poor rural households in the humid tropics whilst slowing down deforestation and enhancing essential environmental services. Poverty reduction in the humid tropics depends on finding ways to raise productivity of labour and land, often through intensification of smallholder production activities. Although there are some opportunities to reduce poverty while conserving tropical forests, tropical deforestation typically involves tradeoffs among the concerns of poor households, national development objectives and the environment (De Fries et al., 2004; Palm et al., 2005). ASB partners work with households to understand their problems and opportunities. Similarly, consultations with local and national policy-makers bring in their distinctive insights. In this way, participatory research and policy consultations have been guiding the iterative process necessary to identify, develop and implement combinations of policy, institutional and technological options that are workable and relevant.

The participatory on-farm work is undertaken at ASB 'benchmark' sites, established in each of the regions. These are areas (roughly 100 km^2) of long-term (i.e. more than 10 years) study and engagement by partners with households, communities, and policy-makers at various levels. All benchmark sites are in the humid tropical and subtropical broadleaf forest biome (as mapped by WWF, the World Wide Fund for Nature). The most biologically diverse terrestrial biome by far, conversion of these forests leads to the greatest species loss per unit area of any land cover change.

ASB focuses on the landscape mosaics (comprising both forests and agriculture) where global environmental problems and poverty coincide. ASB's multisite network helps to ensure that analyses of local and national perspectives, and the search for alternatives, are grounded in reality.

An analysis of the lessons learned in ASB shows that the importance of team- and network-building at each one of the 'benchmark sites' cannot be overstressed. Much care was taken in the selection of research sites representative of the major regions, globally, where slash-and-burn agriculture is important. Each site thus encompasses a broad range of biophysical and socio-economic conditions and is representative of conditions prevailing throughout different regions. Standardized methods for site characterization and for undertaking both biophysical and socio-economic research at each site were designed and discussed with the multi-institutional and interdisciplinary teams at each benchmark site. The core team of scientists who conceived the research agenda of ASB, which includes the need to work in parallel in different sites representative of a range of regional conditions, did not however foresee how difficult the initial team- and network-building was going to be. Even though all the institutions involved subscribed to the ASB research agenda, and had been attracted to the ASB Consortium because they found this research agenda compelling, teams at each site took an average of two years to coalesce. The core team did not foresee that it would take this long for scientists from different institutions and different disciplines to successfully work together in a regional mode, but on global questions. In hindsight this seems naïve, but at the time all the scientists were focusing on the contents of the research and just did not think about what it takes to build a team in one location (let alone in multiple locations in parallel). The transaction costs of learning to work together at each benchmark site were compounded by those associated with the need for overall coordination and communication. The different teams at each site consisted of scientists from research institutions (national and international), from NGOs and from universities. Some had previous experience with participatory research methods; others had none. It quickly became obvious that it was essential to reconcile the objectives of the programme with the expectations of each team member at a given site. The differing roles of these participants required almost constant renegotiations on the part of the overall coordinator.

One dimension of the ASB approach, the use of 'standardized' methods at each site to facilitate cross or interregional analyses of results, proved difficult to implement at first. Each benchmark team considered that the set of methods proposed by the programme needed to be significantly amended to account for the particularities of their own site. The analysis of data across the benchmark areas and the global results were indeed not a very strong motivation for some of these teams, until it was agreed that the global or cross-site analysis would be undertaken by all interested scientists, no matter whether they were located at a given site or were part of the initial core team. A geo-referenced database was developed to facilitate the synthesis of results and the sharing of information across the regional teams. After a few years of data collection at each benchmark area, and once some of the regional results started being analysed from a global perspective, the regional teams became almost more interested in the global analysis than in the production of a full analysis of their own data.

Using integrated scenario analyses for facilitating regional-level analyses

Scenario development and analysis has already been successfully used at a global level to help reveal and address knowledge gaps about the plausible future interactions between GEC and a number of ecosystem goods and services, e.g. food production or water availability or climate regulation. Such studies are often called 'integrated' as they include (i) social, economic and environmental processes and scientific disciplines; (ii) cover multiple levels on multiple scales; and (iii) strongly involve stakeholders. Such scenarios can be either qualitative (stories) or quantitative (models) or both.

Scenario analyses conducted at the regional level help to systematically explore policy and technical options at the appropriate level by providing a suitable framework for (i) raising awareness of key environmental and policy concerns; (ii) discussing viable adaptation options; and (iii) analysing the possible consequences of different adoption options for food security and environmental goals. These can be based on scenarios developed at the global level (e.g. the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (IPCC, 2000); the Millennium Ecosystems Assessment (MA, 2005) and the UNEP's Global Environment Outlooks (GEO-3 and GEO-4: UNEP, 2002, 2007), but such analyses do not necessarily feature issues that are of particular relevance at the given regional level (Zurek and Henrichs, 2007).

Downscaling global scenarios to national (or even local) level has been considered by a number of authors (e.g. Lebel et al., 2006; Biggs et al., 2007; Kok et al., 2007) but, while a commonly agreed approach is still lacking, downscaling methods and theories are becoming more common (e.g. Zurek and Henrichs, 2007). Upscaling has, however, proven to be more difficult and remains one of the largest challenges. Some argue that global downscaling limits the creativity and diversity of regional scenarios and call for more upscaling efforts. Others argue that upscaling will fail because of the lack of a common framework in terms of drivers, time horizon, definitions etc. (see Alcamo et al., 2008). So, while there are a large number of detailed global scenarios available, their potential has been undervalued for developing scenarios at regional level.

The current state-of-the-art is to embark upon a cross-level methodology in which global scenarios are first downscaled and used to produce regional or local scenarios without being prescriptive, after which local scenarios are used to enrich the existing global storylines in an iterative procedure, often using qualitative storylines as well as quantitative models. Creating regional scenarios is not just a matter of 'downscaling' the information available in global scenarios (e.g. climate change projections) for regional use; some information (such as trends in trade) will have been built up from lower levels. Other information will be new and will need to come directly from the region in question (Zurek and Henrichs, 2007). Regional 'storylines' of plausible futures can share some of the key assumptions with global-level storylines, i.e. be coherent with global assumptions, yet regionally 'enriched', as was the case for the GECAFS Caribbean exercise (Box 3). Similarly, the Southern African Sub-Global Assessment (SA*f*MA) (Biggs et al., 2004) adapt existing scenarios, stressing governance as a major driver and developing two regional storylines, African Patchwork and African Partnership. These can be mapped to the MA Global Scenarios.

Box 3 The GECAFS Caribbean Scenarios Exercise.

In 2005, with funding from ICSU and UNESCO, GECAFS, in collaboration with FAO, UNEP, the Millennium Ecosystem Assessment and the European Environment Agency, developed the conceptual frameworks and methods necessary to formulate a set of prototype scenarios for researching the interactions between food security and environmental change at the Caribbean regional level. These scenarios were specifically designed to assist analyses of possible regional policy and technical interventions for adapting food systems to environmental change so as to explore the medium- and long-term prospects for given adaptation options for food security. The innovative operational framework was based on theoretical advances in the notion of food systems and their vulnerability to GEC, and downscaling global scenarios to regional level.

The Caribbean scenarios exercise involved about 30 people including social and natural scientists from regional research institutions (e.g. the University of the West Indies (UWI) and the Caribbean

Institute for Meteorology and Hydrology (CIMH)); social and natural scientists from national research institutions (e.g. universities and national laboratories); policy-makers from regional agencies (e.g. the Caribbean Community Secretariat (CARICOM), Inter-American Institute for Cooperation on Agriculture (IICA)); policy-makers from national agencies (e.g. Ministries of Agriculture); international agencies (e.g. FAO, UNEP); and was facilitated by the GECAFS scenarios group. A number of key steps were involved:

1. Identifying key regional GEC and policy issues, based on an initial stakeholder consultation workshop involving regional scientists and policy-makers.
2. Drafting a set of four prototype regional scenarios (Global Caribbean, Caribbean Order from Strength, Caribbean TechnoGarden and Caribbean Adapting Mosaic) in a first regional workshop, which were then elaborated upon in a follow-up writing exercise by regional authors. These were based on the broad rationale, assumptions and outcomes of the MA scenarios exercise, but allowing for regional deviation where needed.
3. Describing developments per scenario for key aspects of the food system, the focus of a follow-up regional workshop involving most of the first regional workshop participants.
4. Systematically assessing food system developments per scenario, and presenting outputs graphically as part of a second regional workshop. This involved describing the main developments per scenario for each Food Security element, systematically assessing each development per scenario for each food security element, and finally plotting each assessment (see Figure 1).

The scenario exercise delivered a number of related outputs: it integrated (i) improved holistic understanding of food systems (axes on graphs) with (ii) vulnerability (change of position along axes) with (iii) policy interpretation of future conditions (comparing four graphs) with (iv) adaptation insights at the regional level for improving overall food security (where to concentrate effort on enlarging the polygon areas of each graph).

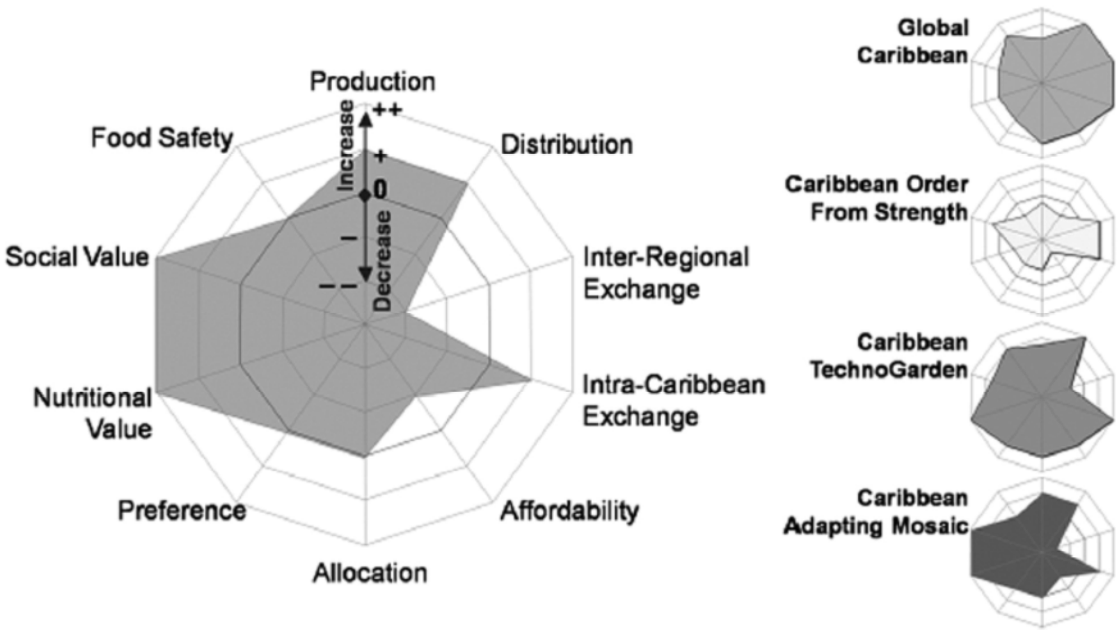


Figure 1 Indicative food security diagrams for four Caribbean scenarios (GECAFS, 2006b)

Methodological challenges for research at regional level

Research undertaken at the regional level embodies a number of methodological challenges that need to be addressed at the outset, otherwise they become bottlenecks. In the biophysical sciences, data collection takes place at specific geographical and physical locations, and therefore at specific points in time. Given the spatial heterogeneity, or the spatial patterns, in most biophysical parameters of relevance to food security and to the interactions between GEC and food security within a region, data needs to be collected using statistical methods that allow extrapolation from a relatively limited number of data points (relative to a whole region). For instance, measures of soil fertility – however a given project defines soil fertility and its measures – need to be collected in such a way that the heterogeneity of soil fertility at the subregional/watershed level is captured, and extrapolation of the measures to a regional picture of soil fertility is feasible and meaningful. This is, in itself, not a straightforward exercise. Methods have been developed to conduct such data collection and analyses of spatial patterns across regions, for instance using geostatistics (Coe et al., 2003).

In food security and GEC studies, this is, however, complicated by the fact that other system parameters within a region (e.g. farmers' access to roads and markets) also vary, but at a different spatial level. As a rule, spatial patterns in biophysical and socio-economic parameters within a region occur over different levels on both spatial and temporal scales. Since the data collected will have to be analysed in an integrated manner to arrive at a meaningful and useful picture of GEC/food security interactions within a region, a 'silo' type of analysis, in which biophysical data are analysed separately from socio-economic data, is not a feasible option.

To enable researchers to conduct a scientifically robust integrated analysis of all the data collected, as is essential in GEC/food security studies, a geographical unit of analysis, which is meaningful from both a biophysical and a socio-economic perspective, needs to be identified by the scientists involved. In the ASB programme, for instance, the scientists finally agreed upon a set of 'land use categories' that were used throughout all the ASB benchmark sites, and that were essential in the extrapolation of the data collected to regions. In the GECAFS work in the Indo-Gangetic Plain, the agreed unit of analysis for each case study was an administrative district.

In addition to these requirements for data collection and integrated analysis of data at the regional level, methods capable of investigating interrelationships among different types of analysis and capable of synthesizing and analysing the key economic, environmental, agronomic and biophysical issues at stake, and at the correct resolutions, are also needed. A range of models and mathematical methods exist that provide relevant tools for this, but all have limitations of course (Coe et al., 2003); van Ittersum and Wery, 2007). Scientists conducting GEC/food security studies thus need to carefully select the most appropriate tools, given the specific objective of their research.

Identifying case study sites

Research designed to address the regional-level, subregional-level and cross-level questions identified above will give insights into how food systems operate across a region, how this diversity affects food security across a region, and what possible adaptation strategies can be considered both locally and for the region as a whole. However, selecting case study sites across a diverse region necessitates a compromise between optimal scientific and practical considerations. One aim can be to build on on-going research infrastructure and research sites, and existing data, rather than establishing research sites *de novo*. An initial useful step can be to survey existing work in the region to see what to build on, and also to show where new studies can add value to others by 'mapping' them onto the research structure of the new study. This type of information can be used to identify research projects for which suitable socio-economic and environmental data are already available, and would help to build up regional research networks (as have been very successfully developed by the Inter-American Institute for Global Change Research, IAI). It would also enable an analysis of existing work that can be integrated to help address the research agenda and to identify where the major gaps appear to lie. Box 4 illustrates the process of case study site selection in the GECAFS work in the Indo-Gangetic Plain.

Box 4 Identifying research sites for multilevel research.

Choosing case-study sites is a critical part of multilevel research, and should ideally be based on discussion among all stakeholders. For GEC/food security research, some selection criteria could include:

- lie-along gradients of, for example, anticipated temperature and precipitation change or current and anticipated grazing pressure;
- sufficient representation of different governance (e.g. land tenure) arrangements;
- sufficient representation of the region's principal farming systems (Dixon et al., 2001);
- sufficient representation of key drivers in regional scenarios (see Box 3);
- building on work where interventions have been shown to be effective.

The aim is to identify a set of sites that are individually representative of the specific subregion/selection criteria, and which, when considered as a whole set, give a good representation of the region overall and the heterogeneity within it. This might need an integrative approach, as proved to be the case in selecting GECAFS research sites in the Indo-Gangetic Plains (IGP).

A workshop was convened to identify five case study sites reflecting the socio-economic and environmental diversity of the IGP. Administrative districts were chosen as this was the unit for which socio-economic data was generally collected. Initial suggestions were presented for a site in each of the five rice-wheat subregions across the IGP (as identified by the Consultative Group on International Agricultural Research (CGIAR)-supported Rice-Wheat Consortium). Criteria included identifying where the effects of various GEC drivers will be most extreme and where those living in poverty will be worst hit. The likelihood of data availability was also an important consideration. When all five sites had been presented, they were considered in terms of balance of GEC drivers and food system variables (so as to assist with synthesizing across the sites), and one different site (in Bangladesh) was chosen. The final set (see Figure 2) captures the heterogeneity across the IGP while also being of relevance to district-level planners.

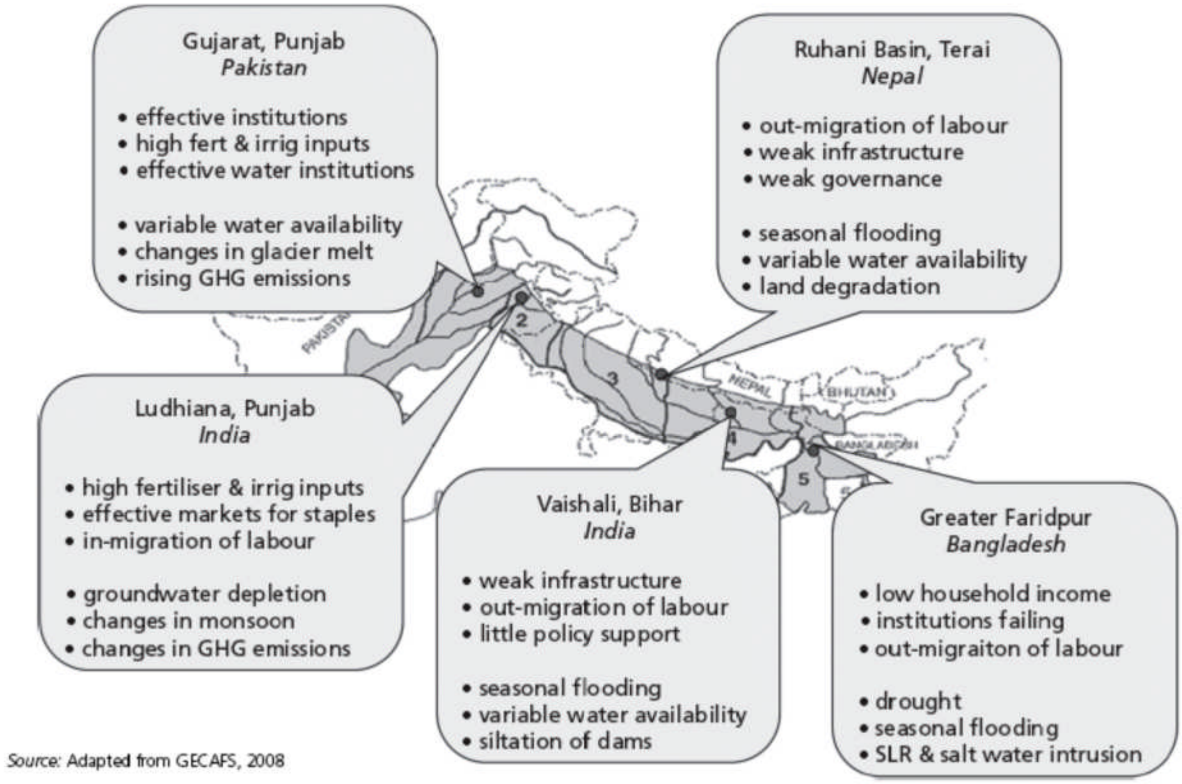


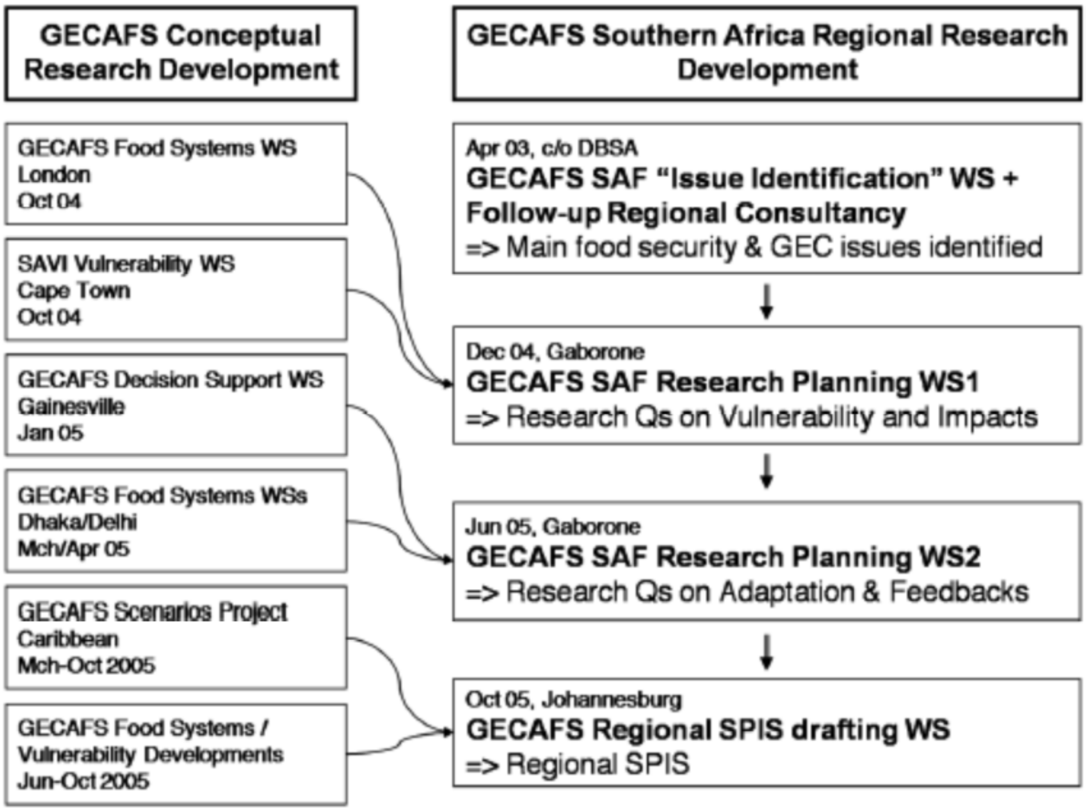
Figure 2 Location of GECAFS-IGP case studies identified in relation to the main rice-wheat growing area and showing major socio-economic characteristics and GEC concerns.

Regional synthesis and integration workshops can draw together case-study research output to address regional synthesis questions. The survey of recently completed, on-going and/or imminent region-wide research activities can indicate which outputs from other projects can be best included in synthesis workshops. An additional approach is to undertake analyses at the regional level of, for instance, market and physical infrastructure, food storage and transport systems, land-use conversion, etc. These give a good insight of the general conditions across the region which cannot be achieved by synthesizing a small number of case studies.

Defining regional research within the international research context

While the emphasis of the paper is the regional level, it is important to remember that research at this level can (and often should) usefully interact with research developments at the global level. This is particularly the case where international research structures exist that can both benefit from and contribute to regional research. The international GEC research programmes (which together form the Earth System Science Partnership, ESSP) are a case in point and there has been considerable mutually beneficial interaction between the GECAFS regional projects (being sponsored by ESSP), and these global endeavours. Such contacts also help with international networking and capacity development. Further, there can be great value gained by the iterative development of the regional (i.e. place-based) and conceptual (i.e. non-place-based) research often more typical of some international endeavours.

Figure 3 shows the process of research development for the GECAFS southern Africa Science Plan and Implementation Strategy, which involved several interactions between regional stakeholders with developments on the conceptual agenda. It also highlights interaction with another GEC research initiative (the Southern Africa Vulnerability Initiative, SAVI). These steps all depended heavily on strong and active stakeholder involvement and considerable effort was taken in ensuring a wide range of participation. Key outputs at each stage were built upon, culminating in an agenda seen as of high regional relevance by major regional agencies (GECAFS, 2006a).



Adapted from GECAFS, 2006a

Figure 3 Development of the GECAFS-Southern Africa Science Plan and Implementation Strategy

Establishing institutional buy-in for GEC/food security research at regional level

Research partners

In addition to identifying a number of researchers who need to come together to bring the necessary range of skills, effective GEC/food security research needs the close involvement of other stakeholders in planning and delivery. While the need for such involvement may be fully accepted, it can be hard to identify the right partners and even harder to engage them meaningfully. One way to help is to try to identify existing institutions which individually can fulfil different key roles in the research. These could, for instance, help to provide scientific visibility and credibility within the region, or act as 'boundary organizations' between the main research endeavour and other, more distant stakeholder communities, e.g. individual farmers. Establishing institutional buy-in from a range of stakeholders can add a powerful dimension to the research itself, and can also be very useful in outreach as such partners are often well connected to a wide range of beneficiaries. Posing a clear question, and drafted in terms to which potential partners can easily relate (e.g. 'how can Southern African food systems be adapted to reduce their vulnerability to GEC?), helps both attract interest and identify the role each can play. Box 5 shows how a range of stakeholders thus 'bought-in' to a GEC/food security research question in the region. The signing of Memoranda of Understanding (MoUs) and/or the formal endorsement of research plans can be a powerful way of demonstrating this buy-in to other potential stakeholders, including donors.

Donors

Several major organizations are now embracing the food systems concept for advancing food security research at regional level. Notable examples include the FAO (2008a), UK government (Defra, 2008), European Science Foundation (ESF, 2009), Dutch government (NWO, undated) and the CGIAR's new initiative 'Climate Change, Agriculture and Food Security' (CCAFS, 2009). Despite this, raising funds for GEC/food security research at regional level is not easy. This can be due to a number of factors.

First, donors are most often mandated to operate on a bilateral basis at a national level and efforts to 'regionalize' projects generally has to involve a synthesis across multiple projects as they come to an end. Also, regional-level projects, and especially those that try to link across spatial and/or temporal levels, can be deemed too unfocussed.

Second, research on food security, let alone when coupled with GEC issues, is highly complex and full of uncertainties. Research designed to 'grasp the nettle' is therefore highly complex and involves a large number of parameters and collaborators. While it might address the stated aims of development agencies better than research on, say, food production, the inherent complexity means it is hard to fit within funding portfolios (which might be structured in terms of agriculture development, policy, governance, science, etc.), and is also deemed 'high risk'.

Box 5 Mapping stakeholder interests in a GEC/food security research.

A major emphasis of GECAFS regional research planning has been the identification of a range of stakeholder groups in each region and the clear mapping of their respective interests in relation to the overall endeavour. Figure 4 maps the key interests of a number of different southern African stakeholder groups in relation to a fundamental GEC/food security question.

The two key collaborative organizations in this example are (i) the International Council for Science Regional Office for Africa (ICSU-ROA), which helps link the science and development agencies with policy-makers; and (ii) the Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN), which helps link the development agencies, policy-makers and resource managers (principally farmers).

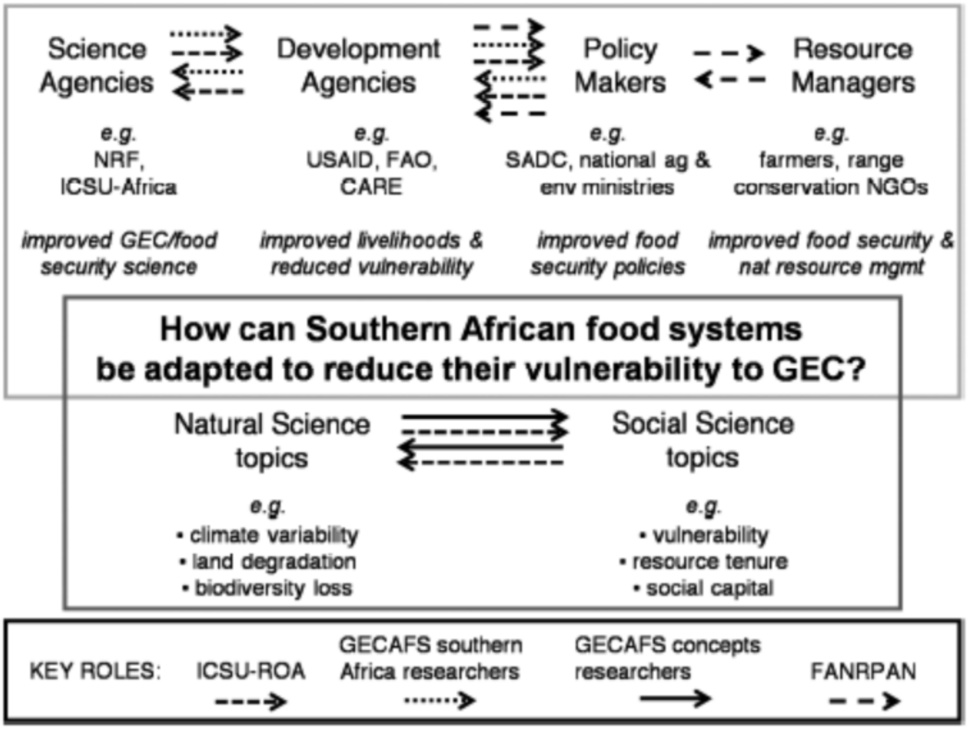


Figure 4 Key interests of a number of different southern African stakeholder groups in relation to a fundamental GEC/food security question

Third, given national agendas and institutional mandates, it can be hard to identify a champion for regional studies who is able to devote the necessary time to lobbying donors and strategic partners. The importance of this aspect cannot be underestimated, as the need to 'persuade' donors not only of the value in what they might see as 'high risk' studies, but also its new research concepts (i.e. the food system, vis-à-vis agriculture) as underpinning food security, takes a great deal of time and energy.

Fourth, research results will only be realized after a few years. This is because most researchers in the food security domain are trained in agricultural issues, and there is a need for a new cadre of researchers to become conversant with food security concepts and food system analysis. Next, the food system(s) need describing and how, where and when they are vulnerable to GEC made explicit. Only then can research on food system adaptation begin in earnest.

Fifth, the complexity of the research coordination and administration necessitates a well-organized organization to host and administer large grant(s). This organization needs a regionally recognized regional mandate, in which donors will need to have full confidence; such organizations might be hard to identify.

Finally, holistic, on-the-ground research, in a number of case studies across a region, over a number of years, is expensive. Experience in the GECAFS regional projects shows that, while donors strongly supported the planning exercises around the world, raising the sums needed for research implementation (1–2 orders of magnitude higher than for planning) has not thus far proved possible.

As political and science pressure grows for action on the GEC/food security agenda, the hope is that donors will begin to support to a greater extent this more complex type of research.

Conclusions and recommendations

There are numerous challenges related to research at regional level: cross-scale and cross-level issues, identifying and integrating results from case study sites, building research networks, establishing institutional buy-in and raising funds. However, these challenges must be overcome as GEC/food security research at the regional level will deliver considerable benefits to a range of stakeholders and ultimate beneficiaries which would not be apparent by restricting research to local or global levels.

Research conducted within AIACC, GECAFS, ASB, RENEWAL and other projects has identified a number of key factors that can help in terms of research framing:

- Three types of research questions (regional-level, subregional-level and cross-level) all need to be addressed to understand the complex spatial and temporal dynamics within a region and to cover the varied policy interests of regional stakeholders.
- A useful initial step is to survey existing work in the region to see what can be built on, and also to show where new studies can add value to others by ‘mapping’ them onto the research structure of the new study. This also helps identify potential members of a research team.
- A geographical unit of analysis, which is meaningful from both a biophysical and a socio-economic perspective, needs to be identified and agreed upon.

It is also clear that for the research to have a good chance of having significant policy-relevant outcomes (i.e. not just science outputs), it is crucial to establish buy-in from regional policy agencies. A number of lessons in this area have also emerged:

- Holding planning meetings in locations where representatives from such bodies would most likely be able to participate helps gain input, and hence an insight into policy interests;
- the establishment of advisory panels including representatives from such agencies helps to ensure ‘in-reach’;
- scenario analyses conducted at the regional level help to systematically explore policy and technical options, and provide a valuable means of integrating the policy dimension;
- having a clear question posed and drafted in terms that potential stakeholders can easily relate to, helps both attract interest and identifies the role each can play;
- the signing of MoUs and/or the formal endorsement of research plans can be a powerful way of demonstrating this buy-in to other potential stakeholders, including donors.

Ultimately, of course, success will depend on establishing good working relationships with a range of stakeholders, so as to set and undertake an agenda that is both scientifically exciting and relevant to improved regional food security policy and resource management.

From Food Production to Food Security:
Developing interdisciplinary, regional-level research

Part IV: Reflections and Conclusion

Why the thesis title and thesis questions are appropriate, and how the papers address the questions

As discussed in the Introduction, attaining food security for all is clearly more complicated than just producing more food; the world produces more than enough food for everyone, yet around one billion people are without sufficient food and millions more are nutrient deficient (Pinstrup-Andersen, 2009). The fundamental issue therefore concerns *access* to nutritious food rather than food production, and this notion is now well accepted as the key factor determining food security (Foresight, 2011). A research agenda to addresses food security therefore has to address a range of issues in addition to food production. These relate to access to food and utilisation of food, as well as to availability of food.

For most people a key factor determining access to food is its affordability. This is dependent not only on food cost but also on the disposable income that can be spent on food. Access is also determined by the way society allocates food to its members (or withholds it, usually for political reasons), and our food preferences. Our food security also depends on the ways in which we use food and its functions; food must fulfil our nutritional needs and must be safe to consume, but it also plays a number of social and religious roles. Food availability is fundamentally dependent on food production, but this can be local or distant. If distant, local food availability will also depend on trade systems, and on packaging, transport and storage. This will all add to the cost to the consumer, unless the cost of production at distance is so much less than locally so as to off-set these additional costs. Other 'costs' however include, for instance, environmental impacts of food transport, and competition for work in the food production sector locally. Better quantification and assessment of all such factors is required to determine the full 'cost' of food.

Finally, and as stressed by (Stamoulis and Zezza, 2003) in relation to the 1996 FAO food security definition, the three major components of food security (availability, access and utilisation) must all be stable over time. Indeed, one definition of food security encompasses the notion of removing the threat of future food insecurity: "A family is food secure when its members do not live in hunger or fear of hunger" (USAID, 2001).

This reorientation of the debate from one dominated by agriculture and food production towards the more holistic notion of food security is captured in the main part of this thesis title "*From Food Production to Food Security*". This title also helps frame the first question asked in the thesis: *What are the essential characteristics of a research agenda to address food security?* The Introduction (Part I) and Papers 1-3 (Part II) address this question by drawing together, and building on, a wide range of issues:

Paper 1 opens the discussion by introducing the notion of 'food provision', a concept of greater relevance to societal well-being, and hence policy making at large, than food production *per se*; it argues for the need to think beyond productivity and production. It then introduces the concepts of the vulnerability of food systems to environmental stress and discusses the impacts of stresses, adaptation to stresses, and feedbacks from adaptation pathways to socioeconomic and environmental conditions. It closes with a call for better tools for analysing the trade-offs between food security and environmental goals in the context of these feedbacks.

Developing the discussion from an agronomic viewpoint, Paper 2 goes on to argue for the need to better understand how climate change will affect cropping systems (in contrast to crop growth); the need to assess technical and policy adaptation options to enhance food production; and the need to understand how best to address the information needs of policy makers. It also introduces the importance of the spatial scale so as to consider food production from a region as opposed to the yield of a particular cropping practice. This helps position research on productivity within the broader context of food security.

The final paper in Paper 3 then argues for, and describes the major characteristics of, the food system concept as developed by the 'Global Environmental Change and Food Systems' (GECAFS) international research project (Ingram et al., 2005). Drawing on rich, but relatively distinct literatures on (i) the food chain and (ii) food security, (Ericksen, 2008a) established this as a key GECAFS product, and a number of national and international organisations have adopted this model for their framework and planning documents (e.g. Defra, 2008; FAO, 2008a; ESF, 2009). The paper goes on to offer five examples where this food system approach helps research on the complex, two-way interactions between food security and environmental change.

Part II therefore determines that the 'essential characteristics of a research agenda to address food security' needs to encompass several components. First, it should be based on a food system approach as this integrates the activities of producing, distributing, trading and consuming food with the food security outcomes derived from these activities, i.e. food access, food availability and food utilisation. It thereby identifies the consequences for food security (and other outcomes) of research on improving the way which various activities are undertaken. Second, inter- and trans-disciplinarity approaches are needed as the complex interactions between the many biophysical and socioeconomic determinants exceed disciplinary viewpoints. Third, the notions of scales and levels must be central to research planning and delivery.

The second part of the title "*Developing interdisciplinary, regional-level research*" is addressed in Papers 3-6, drawing on Papers 1-3 in relation to the need for interdisciplinarity, but also introducing the notion of research at 'regional' level:

The need for, and value of, regional-level research is presented in Paper 4, which addresses the second thesis question "*Why is research at the regional level important?*". It makes the particular case for regional-level research on the interactions between food systems and GEC, identifying and discussing adaptation opportunities that emerge if the region as a whole is considered (as opposed to a number of individual countries). It details the importance of the complex and varied cross-scale and cross-level interactions for food security, and gives examples of 'scale challenges' encountered if these interactions are not recognised and actions taken to overcome them.

The adaptation options identified and discussed in Paper 4 necessarily involve interactions between multiple stakeholders (e.g. government and NGOs; researchers and research funders; and business and civil society). These can relate to, for example, policy-setting, trade, consumer preferences, and regulations. Understanding these stakeholder interactions is crucial in food security research generally, and especially when working at regional-level, and the Paper draws attention to the scale challenges often arising due to the lack of necessary interactions. Paper 5 therefore addresses the third thesis question "*Who needs to be involved in research design and delivery, and how are they best engaged?*" by discussing who the stakeholders are in the GEC-food security debate, when to engage them in research planning, and how. It goes on to discuss interactions with stakeholders to enhance decision support for food security, and how to assess the effectiveness of stakeholder engagement.

The final paper in Part III (Paper 6) then reviews important practical aspects of undertaking research at the regional level. It discusses how to identify the client, how to encourage regional research networks and the importance of team building and standardised methods. It considers the many methodological challenges for research at regional level including the critically-important aspect of establishing institutional buy-in to the research agenda. It shows how participatory research methods such as consultations, surveys and scenario exercises help overcome these.

Collectively, the six papers thereby answer the three interlinked questions posed in Part I of this thesis:

1. What are the essential characteristics of a research agenda to address food security?

2. Why is research at the regional level important?

3. Who needs to be involved in research design and delivery, and how are they best engaged?

Importance of this type of research and its impact on the science agenda

The need for interdisciplinary, even trans-disciplinary, approaches for food security research is now well accepted (Liverman and Kapadia, 2010; UK Global Food Security Programme, 2011). Indeed, food security research provides an excellent example of the need for much enhanced interdisciplinarity, with social science, economics and the humanities all playing critical roles in addition to the biophysical sciences. As Pálsson et al. (2011) state “Accepting that food systems encompass social, cultural, economic and political issues, as well as biophysical aspects, acknowledges contributions of different disciplines. However, in bridging disciplines we must recognize the importance of framing these systems when devising appropriate management interventions, development strategies, and policies”.

The value of the ‘systems’ approach for research on food security

In addition to underscoring the need for contributions from a range of disciplines, the GECAFS food systems approach introduced in Paper 1, and elaborated upon in Paper 3, engenders a greatly enhanced discussion on food security. Paper 3 also documents a range of case studies where the approach has been helpful in planning and undertaking research. The work in these examples stems from a number of more fundamental impacts on the science agenda:

First, and as Ericksen summarises in Ingram et al. (2010), the food systems approach frames the food system activities as “dynamic and interacting processes embedded in social, political, economic, historical and environmental contexts”. It thereby relates the food system activities of producing food, processing, distributing and retailing, and consuming food (the “*what we do*”) to the outcomes of these activities not only for food security and other socioeconomic issues, but also on the environment (the “*what we get*”) (Paper 3, Figure 1). Clearly, this interconnected set of outcomes, and particularly as relating to food security, results from a complex set of interactions in multiple domains but these are often not highlighted in conventional food chain analyses focusing on food yields and flows. The structured integration of the food chain and food security concepts was the key development in the Ericksen paper (2008a), and expanded upon in Paper 3.

Second, by embedding this integrated concept within the socioeconomic and global environmental change drivers and feedbacks discussion initiated in Paper 1, and developed further in Paper 3 (e.g. the ‘Planetary Boundaries’ example), this ‘food systems’ approach enhances the science agenda by explicitly considering feed-backs to both environmental and socioeconomic conditions for given adaptation options – the “so what” question. This has great policy relevance as the intended consequences (the ‘impact’), and (often more importantly) the unintended consequences of a given technical or policy intervention need to be carefully assessed. As Erickson goes on to note, “feedbacks from food system activities are of a particular concern because they may have unintended, and often negative, social as well as environmental consequences. This forces society to confront the trade-offs between key ecosystem services and social welfare outcomes” (Ericksen, 2008a).

This important point about feed-backs motivates analyses of the synergies and trade-offs between varied desired outcomes from food systems. This can be done most effectively if the broad food system approach is adopted. It thus drove the development of a set of ‘feed-back’ questions for the GECAFS regional science plans (GECAFS, 2006a; GECAFS, 2007; GECAFS, 2008) as research agendas had hitherto generally been limited to the impacts of GEC on food production, and the technical – and to some extent, policy – response options in the agricultural domain. It is also a main feature of the scenarios analyses in CCAFS (CCAFS Scenarios Team, 2010; and Paper 3) which are being developed to address the question “How can food security, livelihood and environmental goals all be met for a set of plausible futures for different regions of the world?”.

Third, the food system approach helps frame discussions of vulnerability. Paper 1 introduces the concepts of food system vulnerability, noting the important point that this is determined not so much by the impact of stress, but by the combination of exposure to stress and the capacity to cope with and recover from this stress. The fuller food system concept allows this to be developed further by defining exactly which aspect of the food system (i.e. which activity(s)) are vulnerable to what (cf. the India/Nepal example in Paper 3) and how this affects food security.

Science contributions from integrating the food systems approach with scale concepts

While the ‘food systems’ approach thus enhances interdisciplinary science agendas in several ways, its real value comes in helping to understand the interactions between the multiple scales and levels thereon which characterise how food systems operate in practice.

Gibson et al. (2000), define ‘scale’ as the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon, and ‘levels’ as the units of analysis that are located at different positions on a scale. Cash et al. (2006) build on this, noting spatial, temporal, jurisdictional, institutional, management scales, and the need to recognise the importance of interactions between levels along each of these (e.g. from local to global, or seasonal to decadal). Food security issues span a number of different scales and, as noted in Paper 3, a predominant feature of 21st Century food systems is that they are inherently cross-level and cross-scale.

The importance of spatial, temporal, jurisdictional and other scales and scaling as determining factors in many environmental and food security problems is now well recognised, and both scientists and policy makers are increasingly aware that finding solutions requires consideration of various scales. This is particularly important in relation to governance of complex socio-ecological systems (as exemplified in food systems), and especially as they are dynamic; governance, policies and planning have to consider multiple time levels (“… all people, *at all times*, have physical and economic access …”, (FAO, 1996b).

Integrating the food system concept described in Papers 1-3 with this notion of scales and levels provides a major contribution to the science agenda: it helps understanding of how food systems actually operate by identifying the many and complex cross-scale and cross-level interactions they encompass. It also helps understand why actions and interventions aimed at improving food security can fail:

Building on earlier work on scales and levels (Gibson et al., 2000), Cash et al. (2006) propose the idea of "Scale Challenges". These are situations in which the *current* combination of cross-scale and cross-level interactions threatens to undermine food security and the authors identify three such situations: *Ignorance, Mismatch* and *Plurality*. Paper 4 gives a general example where scale challenges affected famine relief in southern Africa in the early 1990s. However, integrating notions of scale with food system concepts more formally identifies where interventions to enhance food security can be made more effective. Take the case of maize trade in South East Africa. Both formal and informal trading systems operate at different levels in time and space, and can be nested and/or overlapping. For the period 2000-2004, official cross-border trade in the region averaged 134 kt per year (MSU, 2008). Concurrent, informal cross-border trade was estimated at 49 kt for the five month period Apr-Aug 2009 (WFP, 2009) – about the same as the official amount, on an annual basis. These parallel systems gave rise to a number of scale challenges to alleviating food insecurity in the region including (i) formal national and donor food security strategies not necessarily taking account for informal trade (*Ignorance*); (ii) trade barriers and lack of harmonisation of trading systems and tariffs constraining food movements across borders (*Mismatch*); and (iii) both formal and informal trade systems being key to satisfying national food security (*Plurality*).

The integration of these scale challenges within the food systems framework enriches the science agenda by identifying novel ways of conceptualising how food systems operate. It also helps food security planning by revealing where impediments arise to enhancing food system activities, and hence where better formulated interventions are required. Further, it also helps highlight the range of actors who need to be involved in overcoming these impediments. These range from formal structures in regional bodies and national and local government regarding reducing tariffs, customs procedures, quarantine arrangements and other barriers so as to enhance intraregional trade, to informal NGOs and civil society networks in providing social safety nets in times of stress.

Despite the clear importance of, and value to be gained from, considering food system activities and their interactions across scales, and across given levels within and between each scale, scale issues are not generally included in food "security" studies. As Wood et al. (2010) report when analysing food security issues in relation to GEC, international environmental assessments conducted to date tend to focus narrowly on the impacts of changes in temperature and precipitation on agricultural production. These, and other conventional analyses, overlook key issues and linkages such as the impacts of extreme weather events on food storage and transport systems, increases in incidence of pests and pathogens (Gregory et al., 2009), and on food preparation (FAO, 2008a). As such, they miss a number of critically-important social, economic and environmental interactions with food security such food preferences, nutritional content and food safety, let alone the many scale issues related to these and others of the nine food security elements (Paper 3).

Science contributions from taking the regional approach

Paper 4 outlines the benefits of undertaking food security research at the regional level: sub-continental regions are a natural spatial level for studies of social-ecological systems (such as food systems) as they are often defined by shared cultural, political, economic and biogeographical contexts – all key factors in how food systems operate. While many determinants of food security manifest at the full range of spatial levels from local to global (e.g. trade), GEC studies have tended to focus on these two extreme levels (Introduction). Information for sub-global (continental or sub-continental) geographical regions is needed as many food system adaptation options emerge when a regional viewpoint is adopted. Examples include improved regional strategic grain reserves, or harmonised trans-boundary quarantine arrangements to allow rapid movement of food around the region in times of stress.

Framing food security research at the regional level yields interesting research questions, especially relating to regional policy agendas and resource management. Examples include intra-regional food trade arrangements, or governance issues relating to regional water resources or regional biodiversity conservation. However, while the advantages of undertaking research at this level are presented in Paper 4, many of the food security issues are based on socio-ecological interactions that are too complex to study at this level alone because they are dependent on subregional conditions. This gives rise to three inter-related types of research questions (regional-level, subregional-level and cross-level; Paper 6). These all need to be addressed to cover the varied policy interests of regional stakeholders, while recognising the complex spatial and temporal dynamics within a region. Relating each of these three sets of 'level' questions to the notions of (i) impacts, (ii) adaptation options, and (iii) feedbacks from such options (Papers 1 and 3) gives rise to nine sets of questions (as exemplified in GECAFS, 2006a; GECAFS, 2007; GECAFS, 2008). Of the three 'level' types of questions, the subregional ones are the best researched to date. Increased attention should now be given to cross-level (and cross-scale) issues as understanding of the dynamic cross-level interactions is weak – yet these are often paramount in food security issues.

Enhanced methods for stakeholder interaction

As noted above, food systems involve critical interactions at a number of levels on a range of scales, each of which involves its own group or groups of stakeholders. Establishing effective dialogue with these stakeholders is a crucial aspect of food security research, as elaborated upon in Paper 5. Research planning has to recognise these multiple stakeholders and engage with them as appropriate/possible and a range of methods including consultancies, workshops and informal approaches can all be effective. While this stakeholder dialogue can be time- and energy-consuming, this process in itself has three important spin-offs: (i) it helps raise awareness of the GEC issues within the policy and other stakeholder communities; (ii) it helps raise awareness of the policy and resource management issues within the GEC science community; and (iii) it identifies, and begins to build, a team of stakeholders keen to work collaboratively.

A powerful way to facilitate stakeholder involvement is through the use of participatory scenario exercises. These link research activities more closely to actual decision-making processes and have shown considerable potential to provide a mechanism for involving a range of stakeholders and for facilitating communication between them. As discussed in Paper 5, there are three major benefits. First, participants in a scenario development process understand better the issues involved via structured dialogue. Second, scenario exercises offer a 'neutral space' to discuss future challenges as uncertainty about the future has an 'equalizing effect'; no-one can predict the future, thus no-one can be proven 'wrong'. This opportunity for open discussion also helps in engendering mutual respect, understanding and trust, which is crucial for building effective research teams for follow-up activities. Finally, the discussion of, and reflection on, possible future trends can create the ground to reveal conflicts, common views about goals, or different perceptions about today's challenges.

Methodological developments for regional research

While the subsections above have identified numerous contributions to the food security science agenda, and especially when applied to the regional level, the planning, execution and reporting of such research is far from straight forward. This is due to the number of reasons:

First, the stakeholder community at regional level is highly complex, embodying a wide range of different types of actors operating on different scales at different levels. While it is important to recognise this complexity, the primary 'client' for the research does need to be clarified. This could be a regional or an intergovernmental body (e.g. SADC, EU), but these are but one of four main categories of stakeholders (research, government, business and civil society) who operate on a similar spatial resolution (Paper 5). Determining how and when to engage with them is challenging as cultural and institutional factors affecting science-policy relationships (e.g. aims, timescale, success measures, evidence, quality control) often frustrate engagement (Scott et al., 2005). Appreciating this is critical and the systematic steps laid out in Paper 5 (Box 5) help overcome many of these problems. This also helps to establish innovative science plans through co-design. Paper 5 also discusses when to engage stakeholders and provides insights in organizing and understanding the complexity of stakeholder engagement, contributing to the concepts and practice of this area.

Second, while the unit of analysis is defined as the region, research could require identifying a number of case study sites so as to establish, for instance, the heterogeneity of a given variable across the region. Choosing case study sites can be politically and well as scientifically complex, so clear criteria are needed. Contributions to best practise include choosing sites to lie-along gradients of, for example, anticipated temperature and precipitation change or current and anticipated grazing pressure. The sites should also provide sufficient representation of, for instance, (i) different governance arrangements (e.g.

land tenure); (ii) different land management (e.g. principal farming systems); and (iii) key drivers in regional scenarios (e.g. demography).

Third, establishing institutional buy-in at the regional level can be difficult, as it includes negotiating with a potentially wide range of research partners (government labs, universities, NGOs and private sector) and donors. Research on food security, and especially when coupled with GEC issues, is complex and full of uncertainties. It can take time for results to become apparent, which challenges timeframes for funding and the information needs of the 'client'. Co-planning helps all partners grasp these realities, and take an active interest in the project. An example of how and why different communities 'buy-in' to a research agenda in given in Paper 6 (Box 5).

Encouraging regional research networks helps overcome many of these challenges as members of the network bring different skills and contacts to the other stakeholders. Team building can be promoted through the adoption of standardized methods, and the use of the participatory scenario exercises, as discussed above. The use of scenarios methods can also help stakeholders to see the links between spatial levels (global to regional; regional to local), although 'downscaling' and 'upscaling' scenarios both present their own methodological challenges.

The scientific contribution of integrating the approaches: from traditional agronomy to production ecology and agroecology to 'food system ecology'

Lessons from production ecology, agroecology and human ecology

As discussed in the Introduction and Paper 2, much of the work on food security stems from agricultural science generally, and empirical agronomy in particular. Such work has made a massive contribution to enhancing food production and removing the threat of famine for many, and its importance both historically and into the future is clear. The interest in gaining a more mechanistic understanding of food production (and crop growth in particular) has however led to the development of 'production ecology'(van Ittersum and Rabbinge, 1997) and the broader concept of 'agroecology'(Dalgaard et al., 2003). Both have emerged over recent decades as key areas of research and much energy has been directed towards the development of mechanistic models to both explore the impact on crop growth of scenarios of changing environmental conditions and also to challenge theories thereby enhancing model structure.

Production ecology initially considered limitations to crop growth, i.e. what determines productivity, or 'yield'. Attention was first placed on the 'crop system' and in particular on crop characteristics, radiation, temperature and CO_2 as factors that fundamentally define the 'potential' crop growth. Water and nutrients were then incorporated as factors that limit crop growth (i.e. the 'attainable' yield within the 'cropping system'). Pests, diseases, weeds and pollutants were then introduced as factors that reduce crop growth, thereby determining the ‘actual’ yield. The notions of ‘potential’, ‘attainable’ and ‘actual’ therefore differentiate clearly the factors that define, limit or reduce yield, respectively (Bouman et al., 1996; van Ittersum and Rabbinge, 1997). (‘Available’ was later described in the Report “Realizing the promise and potential of African agriculture” (InterAcademy Council, 2004) to recognise that a proportion of the actual harvest was lost post-harvest, resulting in a further reduced amount of food that is actually available for human consumption.)

This production ecology approach was based on the concept of a single limiting factor which, once overcome, would allow growth to increase until it was restricted by another limiting factor (the ‘minimum function’). A number of crop, crop-soil and crop-soil-pest modelling approaches have been developed relating to a range of production situations, i.e. potential, water and/or nutrient-limited (van Ittersum et al., 2003). Differentiating the ‘potential’, ‘attainable’ and ‘actual’ concepts is very useful for application in other areas of research where there also is a set of limiting factors. In the case of carbon sequestration in soils, for instance, soil mineralogy, net primary production and erosion are among major defining, limiting and reducing factors, respectively (Ingram and Fernandes, 2001). A key point about this approach is that interactions between limiting factors are additive not multiplicative.

Dalgaard et al. (2003) define agroecology as “the study of the interactions between plants, animals, humans and the environment within agricultural systems”. The general construct of agroecology is therefore broader than the initial production ecology concept, which was based on a single limiting factor. It does however draw on this, but includes also the ecological notions of interconnectivity, community behaviour and spatial organisation. It builds on the community ecology notion of Clements (i.e. including “higher hierarchical levels than the organism [the plant]”), and the worldview of Tansley, which included both biotic entities and their environment (Dalgaard et al., 2003). In this regard it is also aligned with a fuller notion of production ecology (i.e. including the interactions with livestock), but includes integrative studies not only within agronomy and ecology but also including environmental science more generally. Interdisciplinarity and scaling across spatial levels are both central tenets and the broad agroecology concept thereby helps move the debate towards the needs discussed in Paper 2, and thus towards the broader food security agenda. (The further broadening of both concepts is discussed below.)

It is important to note that the ‘eco’ letters in the word ‘agroecology’ do not denote – let alone advocate – a particular approach, as recommended by De Schutter in his Special Rapporteur report on the right to food, presented to the UN General Assembly in December 2010 (De Schutter, 2010). His argument that agroecology “seeks ways to enhance agricultural systems by mimicking natural processes” is incorrect; agroecology does not seek to mimic ‘natural processes’ but apply ecological principles to help understand how agricultural systems operate and can be better managed. While “integrating crops and livestock; diversifying species and genetic resources in agroecosystems over time and space; and focusing on interactions and productivity across the agricultural system, rather than focusing on individual species” can all be accommodated within agroecological concepts, its “core principles” do not “include recycling nutrients and energy on the farm, rather than introducing external inputs". Agroecology does not advocate organic or low-input agriculture. It is a board concept, providing a framework for investigating the ways of linking a range of inputs (germplasm, nutrients, pesticides, water, energy) with the goods and services we seek from agricultural systems in the context of the natural resource base.

Both the production ecology and agroecology approaches have been further developed to consider factors operating at higher spatial levels, i.e. farm, landscape and even region. Examples include integrated approaches for agro-ecological zonation and regional yield forecasting (Bouman et al., 1996); scenario studies for exploring the effect of environmental or socioeconomic changes on agriculture such as the 'Grounds for Choices' study (Netherlands Scientific Council for Government Policy, 1992; Rabbinge and Van Latesteijn, 1992); for ex-ante evaluation of public policies for sustainable agriculture at landscape level (Parra-López et al., 2009); and for exploring multi-scale trade-offs between nature conservation, agricultural profits and landscape quality (Groot et al., 2007). Interactions with livestock (i.e. the whole farming system) are also critically important in many parts of the word, and particularly in helping farmers cope with uncertainty regarding future threats and potentials (Darnhofer et al., 2010). The boundary between the two approaches are in effect becoming less distinct as researchers move towards addressing problems at regional to global levels, integrating other environmental objectives in addition to food production.

While the production ecology and agroecology concepts have therefore moved well beyond food production at local level towards food availability at higher levels neither, however, addresses the broader issues underpinning food security. For instance, affordability, food allocation and cultural norms, food preferences and the social and cultural functions of food, and food safety, all need to be factored in. This needs additional analyses of the consequences of human activities as a chain of effects through the ecosystem *and* human social system. This is the realm of human ecology, encompassing elements of sociology concerned with the spacing and interdependence of people and institutions (Marten, 2001). As with both production ecology and agroecology, the study of human ecology is composed of concepts from ecology including interconnectivity, community behaviour, and spatial organisation. 'Interaction' is a fundamental concept of human ecology and is a function of scale, diversity and complexity. Together with political economy and entitlement relations, human ecology has been seen for some time as a causal structure of food system vulnerability, and hence food insecurity (Bohle et al., 1994). Concepts from human ecology are very relevant for food systems analyses given the importance of the linkages between the wide range of actors involved and the outcomes of their varied activities.

'Food system ecology' based on integrating concepts

Food security planning can be enhanced by integrating concepts from production ecology, agroecology and human ecology with concepts of food systems and scales.

Understanding the interactions between the many activities and associated stakeholder communities operating in food systems on a range of scales and levels can be helped by drawing on ecological notions of interconnectivity, community behaviour and spatial organisation. Valuable lessons can be learnt from production ecology in terms of the 'defining', 'limiting' and 'reducing' factors for some of the nine individual food security elements in Paper 3 (Figure 1; Box 1), notably production, distribution, affordability and nutritional value. However, and unlike the production situations discussed above, these are not necessarily additive when taken across the whole food system. Factors affecting food system elements interact in a multiplicative (rather than additive) manner, especially if they are, in turn, affected by an overarching, exogenous driver. For instance, an increase in the world oil price will directly – and concurrently – affect a number of food security elements for economic reasons: food production, due to fertiliser price; food distribution, due to fuel price; food preference, due to cost of food; and/or food safety, due to cost-saving in the energy-intensive cold chain. The effect is greater than the 'sum-of-the-parts' due to the feedback interactions among the parts. There is no single limiting factor as such; several interact to impact food security.

As discussed in Paper 4 and above, the notion of scales and levels is critically important in food security discussions. From the production viewpoint, Kropff et al. (2001) note that agronomic systems have pronounced spatial and temporal dimensions: spatial aspects can be distinguished at crop, field, farm, regional and higher levels, while processes at each spatial level have characteristic temporal components. These can span from daily (regarding crop growth) to decadal (regarding soil organic matter dynamics at plot level, or land use change at landscape level). These scaling aspects are taken up by both the production ecology and agroecological approaches discussed above. Both have also developed greater interdisciplinarity, another essential feature of food system analyses. As Gibson et al. note (2000), there is a growing need for interdisciplinary work across the natural-social science divide and this requires each to achieve some common understandings about scaling issues. A food system approach to food security research helps in this regard.

Ecology deals with the relations and interactions between organisms and their environment, including other organisms. Research on food systems and food security can also effectively build on the notion of 'interactions', central to both agroecology and human ecology. Dynamics, interactions and feedbacks which occur at multiple levels on several scales is a major feature of food systems (Ramalingam et al., 2008; Thompson and Scoones, 2009), and many of the ecological principles upon which production ecology, agroecology and human ecology draw also apply. Food systems (i) embody key interactions within the biophysical sphere, the socioeconomic sphere, and the interactions between both spheres (Paper 3; Figure 2); (ii) exhibit a high degree of complexity of interactions (Paper 3); (iii) span multiple scales and levels (Paper 4); and (iv) have a large diversity of activities and actors (Paper 5). In that food systems strongly involve – indeed depend on – relations and interactions between actors and their environment, research can be thought of as 'food system ecology'.

Strengthening policy formulation and feedbacks to the science agenda

Not all research need have direct value to policy formulation, whether this be formal, governmental policy or policy for a business or civil society group. If, however, the value to policy formulation is a prime motive of the research (as is often the case in food security research), the information needs of the policy makers needs to drive research design. This means that setting a food security research agenda needs a highly consultative and inclusive approach, engaging with a range of stakeholders (Paper 5). It also needs to recognise the complexity of stakeholder needs and interactions. Further, and if conducted in the developing world, the links to the development agenda, and particularly to the Millennium Development Goals, must be explicit.

Real research impact will occur only once intended beneficiaries see the benefits of making such changes. From the policy perspective, these benefits must therefore be deemed important, relevant and likely to happen. In addition, potential beneficiaries need to understand and trust the research process – and this will most likely be the case if stakeholder engagement is a fundamental aspect of research. But an indispensable condition for a successful stakeholder dialogue is a shared sense of urgency and ambition; all participants should feel the need to solve the problem that is at stake and to make concrete steps in that direction. They also need to see where the specify research project fits within the broad food security agenda and the food system approach can help in this regard.

As noted above, the approach is also being increasingly accepted by a range of organisations and national agencies in setting policy and calling for new research. It is recognised as bringing structure to the necessary science/policy dialogues, highlighting the fact that food security policy needs to be set cognisant of the range of information needs over different temporal and spatial levels. The dialogues with the policy process also challenge the research community to develop projects which require enhanced interdisciplinarity and novel approaches. A key message for science and policy is that the multiple pathways to achieve greater synergy between enhanced food security and improved environmental outcomes require more coordination than presently exists.

Future research needs

Food systems, and analyses of food security which they underpin, provide a rich ground for research. While there is a long list of research questions in agricultural science (e.g. Pretty et al., 2010), there is a major need to extend the research agenda in non-agricultural aspects, as noted in Paper 3. Technical fixes alone will not solve the food security challenge and adapting to future demands and stresses requires an integrated food system approach, not just a focus on agricultural practices. Two areas therefore warrant particular attention: improving input use efficiency within other food system activities, i.e. across the whole food system; and enhancing food system governance.

Improving input-use efficiency across the whole food system

The food system approach discussed in this thesis helps identify where input-use efficiency can be increased. Regarding the 'food producing' activity, future intensification (including the use of improved germplasm via genetic modification), must seek to increase the efficiency of use of added inputs while minimising adverse effects on the environment. This is especially necessary so as to minimise the contribution of producing food to crossing the 'planetary boundaries' (Paper 3), and innovative production methods will need to be developed.

Gregory et al. noted (2002) the need to reduce the loss of nutrients from fertilisers and manures, and increasing the efficiency of water utilisation in crop production, but pointed out these were challenging objectives. The need to improve the efficiency of inputs in agricultural systems is still well recognised and research necessarily continues to be focussed on these goals. Main attention is targeted towards nitrogen (e.g. Hirel et al., 2007; Ahrens et al., 2010), water (e.g. Hsiao et al., 2007; Blum, 2009) and energy (e.g. Nassiri and Singh, 2009). Other necessary research avenues involve better coupling of plant and animal components in agricultural systems to optimise input use efficiency.

The need to increase the efficiency with which we translate scientific knowledge to the farmer and other resource managers is also well recognised, but it is beset with methodological challenges; how do we define knowledge; how do we engender better 'uptake'; how do we measure success? Given the massive investment in agricultural science, work on 'knowledge-use-efficiency' warrants a major effort. Falling largely in the social sciences, this would add great value to what is currently a biophysically-dominated agenda.

There is also a need to understand how to increase input use efficiency across other areas of the food system. The use of energy and water needs to be optimised in transport and storage (especially in the cold chain); in food processing; in retail; and in consumption. Paper 3 details many of the environmental impacts associated with the full food system but perhaps the most pressing need is to reduce waste.

Waste occurs in all food system activities. In food production, estimates range from 8-22% of cereals wasted at farm-level and post-harvest due to poor storage (Bala et al., 2010), to nearly 100% in some situations for horticultural produce (Parfitt et al., 2010), although this is usually termed post-harvest 'loss'. Over 40% of marine fisheries is wasted as by-catch (Davies et al., 2009).

Parfitt et al. (2010) also note seven other stages in the whole food system where food is wasted, not least post-purchase. They estimate that 25% of food purchased (by weight) is currently wasted per year in UK households, up from 1-3% immediately pre-Second World War. Given the economic, environmental and ethical costs this waste must be reduced, and research is urgently needed on how to improve consumer perceptions and attitudes to waste, especially given the power now vested in the major food retailers (Grievink, 2003; Schilpzand et al., 2010).

Reducing waste across the whole food system will increase the amount of food available for human consumption for the given level of inputs, thereby improving input use efficiency.

Enhancing food system governance

As Brown and Funk (2008) point out, “Transform agricultural systems through improved seed, fertilizer, land use, and governance, and food security may be attained by all”. The authors thus draw attention to the need for enhanced governance in the food producing activity, but in fact this applies both within and between to *all* activities in the food system; poor governance anywhere in the food system (be it related to political, economic or social aspects) is often a major factor contributing to food insecurity.

The inherent cross-level and cross-scale nature of 21st Century food systems means they involve multiple actors and stakeholders. This is due, in part, to the globalization of food systems, the increasing power of large private sector companies and new roles of NGOs in, for example, organics and certification. Related to this, one of the most significant recent trends in food systems is the increasing importance of private sector and non-governmental actors in governance – the formal and informal rules, institutions and practices that guide the management of food within a complex network of governments, organizations and citizens (Biermann, 2007). As Schilpzand et al. (2010) note, this shift in governance towards non-state actors has been “deeply shaped by several broad trends associated with recent patterns in economic globalization”. They identify five major drivers including: (i) the diminishing regulatory authority of nation-states and the tendency for them to shift into facilitative roles; (ii) conversely the growing authority and ‘regulatory’ role of large corporations, particularly through supply chain management and private contracting, which is also often described as ‘private rulemaking’; (iii) the spread of corporate social responsibility (CSR) doctrine and practices, as well as an explosion of public-private or social-private alliances; (iv) a parallel growth in the role of NGOs at all levels of governance; and (v) the emergence of global networks as a key cross-cutting organizational form, and the way in which global supply chains have become the focus of regulatory efforts.

Food system governance is hence highly complex, further complicated by differing understanding of scales and levels and a range of governance approaches. Termeer et al. (2010) address the need to “disentangle” governance complexity by identifying three types of governance: ‘monocentric’ (the dominating formal structures), ‘multilevel’ (many examples emerging) and ‘adaptive’ (relatively new and less experience). They note that adaptive governance has the “ambitious goal of developing new governance concepts that can handle the inherent complexity and unpredictability of dynamic social-ecological systems”. It may therefore be the most appropriate for food security research as it accommodates the complex interactions between social and ecological systems. More importantly, however, adaptive governance focuses on the range of scales and levels inherent in food systems and notes both the importance of, and problems arising from, the cross-scale and cross-level interactions.

Another classification of multilevel governance approaches differentiates between Type 1 (general-purpose jurisdictions; non-intersecting memberships; jurisdictions at a limited number of levels; and a system-wide architecture at a limited number of levels) and Type 2 (task-specific jurisdictions; intersecting memberships; no limit to the numbers of jurisdictional levels; and flexible design) (H. Schroeder, *pers comm*). Type 1 emphasizes the multiple tiers at which governance takes place, and is focused mainly on the administrative units of municipality, province and national government. This is akin to the 'monocentric' system described above. Type 2 includes networks and partnerships between public and private actors across levels of social organization and is more akin to the 'adaptive governance' described above. It includes both formal and informal rights, rules and decision-making processes.

But however 'appropriate' 'adaptive governance' or 'Type 2 governance' may seem, they still have to operate within and/or alongside the formal monocentric / Type 1 governance systems that typify many contemporary societies. How can these two systems co-exist to maximum advantage? Boundary organisations (Holmes et al., 2010) and boundary agents (i.e. individuals) are needed who can span the two governance systems.

This problem of the additional complexity of different governance systems can often be seen when there is a food 'scare', and especially when compounded by cross-scale and cross-level challenges. These usually arise suddenly and attract high media interest demanding a rapid 'policy' response from the establishment (see Box 1, below).

Prompted by the increasing dominance of the major food retailers in the food system (as noted above), further governance questions relate to the location and concentration of power and role of marketing in changing consumer behaviour regarding diet and waste. The need to modify diets for health reasons and reduce waste for environmental, financial and ethical reasons of has a strong governance aspect: who is responsible for bringing about change and what governance approach will be most effective?

Finally, food system governance is increasingly important in relation to the growing environmental agenda. Liverman et al. (2009) identify three governance questions which arise when analysing food systems. The first includes the extent to which concerns about food systems are incorporated into global and regional environmental governance. As the full set of food system activities and food security outcomes are poorly represented in environmental assessments (Wood et al., 2010), they are not highlighted in the discussions around either adaptation or mitigation agendas in the UNFCCC process or in environmental components of regional trade agreements. The second concerns the ways in which the governance of the food system affects the earth system, for instance how the shifts to long global supply chains controlled by large private firms affect climate and land use. The third considers the inadvertent impacts of governance on food systems, for instance the interaction between biofuels, energy efficiency or carbon sequestration projects and food security.

Enhanced research on food system governance clearly has many interesting and highly useful avenues to explore and would be a major contribution to alleviating food insecurity.

Box 1 The *E. coli* outbreak in Germany, June 2011: an example of multi-level food system governance failure regarding food safety.

The response to *E. coli* outbreak in Germany in June 2011 is a good example of the complexity multi-scale, multi-level interactions bring to food safety aspects of food system governance. It highlights – in this case – monocentric governance failings. The contamination was initially thought to have come from the import of Spanish produce into Germany (later proved wrong) and thereby spanned spatial and jurisdictional levels. At European level, the aim is to promote trade between member states, but also to have public food safety systems for the region in place. National food safety and health agencies are only mandated to operate within the national boundaries, i.e. on a different jurisdictional level. With the health problem being largely confined to the Hamburg region, the local health management had to address the immediate health problem. All these levels have a monocentric system in place, operating at the respective level. Given these three distinct spatial and jurisdictional levels, it is hard to establish who is in charge of managing the situation, and what the formal lines of communication are. The monocentric approach did not appear able to deal with the multi-level emergency.

As reported in a Leading Article in *The Independent* (11 June 2011) the *E. coli* outbreak exposed flaws in food system governance in Germany and in Europe: "Germany's federal structure, in which most responsibility for health is devolved to individual states, may be a factor in the ill-co-ordinated response. … Nor was the EU well equipped to compensate for failings at German national level. EU officials could do little more than watch as the Germans and Spanish traded insults, even though the *E. coli* outbreak was claiming victims across Europe and growers not only in Spain faced ruin". The cross-level interactions within the food system, spanning multiple food system activities affecting food system outcomes related to food safety, food production and livelihoods could perhaps have been better managed had an adaptive governance system been in place, or rapidly arisen. Health researchers could have communicated informally with each other and with growers, possibly ascertaining the source of contamination more quickly. This "adaptive governance" approach proved successful in the case of the SARS outbreak in SE Asia in 2006, where an informal network of scientists provided a faster 'solution' than the formal monocentric systems at the international and national levels (C. Termeer, *pers comm*).

Practical challenges to implementing food security research

The sub-sections above identify many conceptual scientific challenges to improving food security. Methodological challenges also arise, and although several are discussed in Paper 6, a few are worth stressing here, in the context of the scientific advances and challenges identified above:

Developing research agendas in support of food security policy formulation needs to recognize that setting such policy is complicated, needs systematic analysis which cuts across scales and levels, and is only going to become more complicated under the pressure of GEC. Research agendas therefore need to be flexible to be able to respond to new needs as adaptation agendas develop, while maintaining communication amongst policy-makers, resource managers and researchers working at a range of levels on varied scales. This can be uncomfortable for researchers accustomed to setting a research agenda and pursuing it to conclusion.

Although transaction costs can be high for all involved, the engagement of as wide a range of stakeholders (e.g. researchers, policy agencies, civil society, the business community and donors) as possible is needed in all stages of such studies. (In practice, as there are potentially many, this might mean identifying the *key* stakeholders.) This helps to establish the expectations and information needs of all stakeholders early in research planning and maintains their buy-in during the research process, thereby helping to establish and maintain credibility, achieve practicality, demonstrate utility, provide accessibility and ensure acceptability of research. However, these stakeholder groups are not well integrated despite the fact that many of the potential adaptation options for enhancing food security will require close collaboration between them. While many regional policy agencies have a clear food security mandate, and while there may be a clearly-expressed need for food security research for a given region and/or by a given body, it can be hard to identify with whom to actually engage. Further, once identified, the key individuals may be already overcommitted and/or responding to immediate crises; engaging key stakeholders can be difficult.

An additional challenge, and as noted in Holmes et al. (2010), is that the science-policy/knowledge-action interface is “difficult land to navigate, a site of competing knowledge claims, suffering severe communication problems as a result of the different languages, norms and cultures found on either side of the complex and blurred boundary between ‘science’ and ‘politics’”. The emergence in recent decades of ‘boundary organisations’ that aim to help bridge between the science endeavour and policy and other stakeholder communities has helped considerably and boundary organisations will continue to be a key component of food security research and policy formulation.

Finally, it is important to note that the nature of the science discussed above is expensive. Raising the sums needed for research implementation (which can be one to two orders of magnitude higher than for research planning) is very challenging. As political and science pressure grows for action on the food security agenda, the hope is that science agencies will begin to support to a greater extent this more complex type of research (the developments within the Belmont Forum (Belmont Forum, 2011) are very encouraging in this regard); and that science agencies and development agencies will work more closely together on common agendas thereby offering larger – and more effective – funding opportunities.

Policy and decision-makers who struggle daily with meeting both food security and environmental objectives must be involved in setting research agendas and including the private sector is also increasingly important. But coping and adaptation require changing behaviours. Real research impact will only occur once intended beneficiaries see the benefits of making such changes. Creating an approach to respond to food security issues needs to be sufficiently sophisticated and nuanced but not so complex as to be unachievable.

Future institutional needs

As the importance of interdisciplinarity emerges ever more strongly, research needs to build on the wealth of disciplinary studies which have characterized most food-related research to date. New interdisciplinary agendas need to be set to move research forward based on an integrated framing of the issues and challenges involved in the food security debate. These research agendas need to be determined by a range of stakeholders which includes the policy and decision makers who struggle daily with meeting both food security and environmental objectives. Implementing them however needs the correct research 'environment', adequately grounded in appropriate institutional research infrastructure.

The need for a new institutional framework to support GEC-food security research

Food security research requires an institutional setting conducive to engendering an interdisciplinary approach. The GEC-food security work discussed in this thesis was initiated in the late 1990s, when the Chairs and Directors of the then international GEC Programmes (IGBP, IHDP and WCRP) saw the need for an additional type of research structure more geared towards issues of greater interest to society at large (Ingram et al., 2007b). This needed greater integration of disciplines. While some researchers had been developing research based on integrating several disciplines (for instance the Theoretical Production Ecology group in Wageningen University) this approach was a new departure for the international GEC Programmes which had thus far been based on disciplinary lines.

Despite this accepted vision, and the development of the Earth System Science Partnership (ESSP) of the Programmes (and now including DIVERSITAS), the institutional framework of Programmes + Partnership still does not provide the necessary institutional framework for delivering research to address complex issues exemplified by 'food security'. The current structures remain an impediment to progress as (i) governance of the varied disciplinary elements (Core Projects) is still mainly located in the respective Programmes and the "look across" the disciplines needed to promote interdisciplinarity is hard; and (ii) it is difficult for non-research stakeholders to engage with all the individual Programmes. The need for a new, unified institutional framework to food security research is urgently needed and especially in relation to integrating GEC studies with other food security research. This warrants a single, multidisciplinary GEC Programme with a governance structure driven by societal-level questions of the day (e.g. food security) rather than by the existing institutional constituencies.

The renewed approach to interdisciplinary research aimed at 'Big Questions' is well encapsulated in the International Council for Science (ICSU) 'Visioning Process' and this points a strong way forward for international GEC science. The need for enhanced food security research provides an excellent rationale for this new way of working, drawing on both the need for interdisciplinarity and broad stakeholder engagement. The on-going structural reorganisation in the Consultative Group for International Agricultural Research (CGIAR) can reinforce this vision, applying it specifically to the developing world's agriculture and food security research in the GEC/sustainability context through the CGIAR Research Program 7 'Climate Change, Agriculture and Food Security' (CCAFS).

Risks with maintaining the status quo

Failure to agree a new research infrastructure brings two risks.

First, it risks holding back the enhanced interdisciplinary research agenda and innovative stakeholder partnerships needed to develop a novel way of producing scientific knowledge (i.e. its 'co-production'), and benefit from this: the so called 'Mode 2 research' (Gibbons et al., 1994). Second, and the 'flip side' of the first concern, is that it risks maintaining the food security agenda in 'Mode 1 research', characterised by the "hegemony of theoretical science; by an internally-driven taxonomy of disciplines; and by the autonomy of scientists" (Nowotny et al., 2003).

The discussion above, supported by the Papers comprising this thesis, call for a more holistic research agenda and advocate a more integrated way forward. It will not be easy without a visionary institutional framework.

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The central message of this thesis is clear: an innovative research approach that integrates a wide range of concepts and methods, disciplines and research cultures, and research funders and commercial investors is needed to enable science to support food security policy formulation and resource management more effectively. This will require enhanced interdisciplinarity, stronger stakeholder engagement, more flexible funding opportunities and an institutional environment with a visionary governance structure.

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Summary

Background

Food is a fundamental human need and achieving food security is of paramount importance to society at large. Driven by the requirement to feed ever increasing human demand, major scientific and technical advances have been made in the production of food. However, despite tremendous success in maintaining food production ahead of *per capita* need on a global basis, history shows that increasing production alone does not satisfy food security for all: in 2010 about one billion people were food-insecure. Production alone is manifestly not the only factor.

Food security is a state or condition. While earlier definitions of food security stressed food production, a commonly-used definition stemming from the 1996 World Food Summit states that food security is met when "*all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life*". The emphasis changed from increasing food production to increasing access to food for all.

Food security concerns have recently rapidly ascended policy, societal and science agendas driven the growing realisation of the scale of future requirements: 50% more food will be needed by 2030, and possibly 100% more meat by 2050. While a large proportion of the discussion under the food security banner continues to address issues related to food production, when addressing food security it is crucial to take a broad view, including – but not being limited to – the fundamentally-important part that producing food plays; the impact of the 2007-08 food price spike underscored the concept of economic access to food being critically important, rather than food supply *per se*. Meanwhile, it is now clear that climate change will affect crop growth in many parts of the world, with the most deleterious impacts anticipated in the developing regions. New concepts, tools and approaches are clearly needed to address the broader food security agenda. Their development is all the more urgent given the additional complications that global environmental change (GEC, including climate change) is already bringing to the many for whom food security is already far from easy. Addressing the complex nature of food security requires greatly enhanced interdisciplinarity, with social science, economics and the humanities all playing critical roles in addition to the biophysical sciences.

The late 1990's saw the emergence of an international GEC research project (Global Environmental Change and Food Systems, GECAFS, 2001-2011). The goal of GECAFS was "*to determine strategies to cope with the impacts of global environmental change on food systems and to assess the environmental and socioeconomic consequences of adaptive responses aimed at improving food security*". GECAFS planning recognised that research to address this challenging goal needed to be set within the context of food systems, rather than just agricultural systems. This helped to identify and integrate the links between a number of

activities “from plough to plate”, including producing, harvesting, storing, processing, distributing and consuming food. The consequences (or outcomes) of the activities for the well-established food security components of *food availability*, *access to food* and *food utilisation* need to be considered, all of which need to be stable over time.

GECAFS research towards this framework culminated in the ‘GECAFS Food System’ concept. Further, and recognising that most food security research was limited to global and local assessments, GECAFS development concentrated on how to integrate environmental and socio-economic drivers and outcomes at the ‘regional’ level. It also became increasingly clear that numerous actors (including the increasingly-important ‘non-state actors’) operate at the regional level, working across a wide range of scales and levels.

Thesis questions and Papers

Against this background, this thesis addresses three questions:

1. What are the essential characteristics of a research agenda to address food security?

2. Why is research at the regional level important?

3. Who needs to be involved in research design and delivery, and how are they best engaged?

These questions are addressed by drawing on a set of six Papers published over recent years and synthesising the main elements of each to help promote innovative and effective food security research for the future.

Following an introduction to the issues (Part I), the first set of three papers (Part II) describes the development of a more integrated approach to food security research. Paper 1 introduces notions of food provision and interactions with the environment, initial food systems concepts and concepts of food system vulnerability. Paper 2 lays out the need to better understand how climate change will affect cropping systems and discusses the importance of spatial scale and the position of crop production in the broader context of food security. Paper 3 lays out the GECAFS food system concept, differentiating clearly between food system *Activities* and food security *Outcomes*. It includes a number of examples of when, how and why a food system approach helps in understanding food (in)security and framing research.

The second set of three papers (Part III) makes the case for research at the regional-level and the need for broad stakeholder engagement. Paper 4 discusses why the regional level is important for food systems and food security/GEC research, and argues for moving research from local to regional. It highlights the range of cross-scale and cross-level interactions that determine food security and gives some example of “scale challenges”. Paper 5 identifies the stakeholders in the GEC-food security debate, discusses when to engage them in research planning and how, and identifies elements of good practice in stakeholder engagement.

Finally, Paper 6 brings together the previous papers by ‘translating’ theory into practice at the regional level. It discusses how to identify the ‘client’ at this spatial level, and describes how to encourage regional research networks and the importance of team building and adopting standardized methods. It concludes by laying out some methodological challenges for food systems research at the regional level, including funding issues and how to establish institutional buy-in.

Reflections and conclusion

The essential characteristics of a research agenda to address food security (*Thesis Question 1*) encompass several components. First, it should be based on a food system approach which integrates the food system activities and the food security outcomes (food access, food availability and food utilisation) derived from these activities. Second, inter- and trans-disciplinarity approaches are needed as the complex interactions between the many biophysical and socioeconomic determinants exceed disciplinary viewpoints. Third, encompassing the notion of a range of spatial, temporal, jurisdictional and other scales and levels on each must be central to food security research planning and delivery. Research at the regional-level is not as prominent as at global and local levels, yet significant adaptation options manifest at this level. However, the effective implementation of such options necessarily involves complex interactions between multiple stakeholders. Understanding these interactions is crucial in food security research generally, but ‘scale challenges’ often arise due to the lack of necessary interactions. It is therefore important to identify who the stakeholders are in the GEC-food security debate at regional level, when to engage them in research planning, and how. Participatory research methods such as consultations, surveys and scenario exercises are effective ways to achieve this.

Framing food security research at the regional level yields interesting research questions, especially relating to regional policy agendas and resource management. Examples include intra-regional food trade arrangements, and governance issues relating to regional water resources or regional biodiversity conservation. Undertaking food security research at the regional level is important (*Thesis Question 2*) as a range of adaptation opportunities emerge if the region as a whole is considered including, for instance, enhanced logistics and establishing strategic food reserves. However, as noted above, food systems involve critical interactions at a number of levels on a range of scales, each of which involves its own group or groups of stakeholders. Establishing effective dialogue with these stakeholders is a crucial aspect of food security research (*Thesis Question 3*) so as to understand their range of world views, aims and constraints. Research planning has to recognise these multiple stakeholders and engage with them as appropriate/possible, and a range of methods including consultancies, workshops and informal approaches can all be effective. A powerful way to facilitate stakeholder involvement is through the use of participatory scenario exercises.

The importance of scales and levels in food security issues needs to be better recognised. Integrating the food system concept with this notion of scales and levels provides a major contribution to the science agenda: it helps understanding of how food systems actually operate by identifying the many and complex cross-scale and cross-level interactions they encompass. It also helps understand why actions and interventions aimed at improving food security can fail due to situations in which the *current* combination of cross-scale and cross-level interactions threatens to undermine food security in three situations: *Ignorance, Mismatch* and *Plurality*.

In addition to underscoring the need for contributions from a range of disciplines, the food systems approach engenders a greatly enhanced discussion on food security. It frames the food system activities as dynamic and interacting processes embedded in social, political, economic, historical and environmental contexts; it relates the food system activities (the "*what we do*") to the outcomes of these activities (the "*what we get*") not only for food security and other socioeconomic issues, but also on the environment; and it helps frame adaptation discussions by identifying which aspects of the food system are vulnerable to what stresses. Finally, the approach enhances the science agenda by explicitly considering feed-backs to both environmental and socioeconomic conditions for given adaptation options. This has great policy relevance as the intended consequences (the 'impact'), and (often more importantly) the unintended consequences of a given technical or policy intervention need to be carefully assessed.

The notion of 'food system ecology' is developed by drawing on lessons from production ecology, agroecology and human ecology. The interest in gaining a more mechanistic understanding of food production (and crop growth in particular) led to the development of 'production ecology' and the broader concept of 'agroecology'. The former is oriented towards optimization of agroecosystems to fulfil production aims based on using best ecological insights, and a number of crop, crop-soil and crop-soil-pest modelling approaches have been developed relating to a range of production situations, i.e. potential, water and/or nutrient-limited.. The latter, incorporating both agroecosystems and other ecosystems at landscape level, has multiple aims including other ecosystem 'goods and services'. Interdisciplinarity and scaling across spatial levels are central tenets in both approaches, and the broad agroecology concept thereby helps move the debate towards the broader food security agenda.

While the production ecology and agroecology concepts have therefore moved well beyond food production at local level towards food availability at higher levels neither, however, addresses the broader issues underpinning food security. For instance, affordability, food allocation and cultural norms, food preferences and the social and cultural functions of food, and food safety, all need to be factored in. This needs additional analyses of the consequences of human activities as a chain of effects through the ecosystem *and* human social system. This is the realm of human ecology, concepts from which are very relevant for food systems analyses, given the importance of the linkages between the wide range of actors involved and the outcomes of their varied activities. This is because food systems strongly involve – indeed depend on – relations and interactions between actors and their environment. They (i) embody key interactions within the biophysical sphere, the socioeconomic sphere, and the interactions between both spheres; (ii) exhibit a high degree of complexity of interactions; (iii) span multiple scales and levels; and (iv) have a large diversity of activities and actors.

Integrating concepts from production ecology, agroecology and human ecology with concepts of food systems and scales leads to the concept of ‘food system ecology’. Developing food security research based on this ‘food system ecology’ helps identify priorities for research investment. Two areas warrant particular attention: improving input use efficiency across the whole food system; and enhancing food system governance.

Main attention for improving input use efficiency in food systems is targeted towards nitrogen-, water - and energy-use efficiency in the agricultural sector. Research often employs production ecological approaches applied at crop, cropping systems, farming systems and land use levels. Other necessary research avenues involve better coupling of plant and animal components in agricultural systems to optimise input use efficiency. However, the use of energy and water also needs to be optimised in transport and storage (especially in the cold chain); in food processing; in retail; and in consumption. However, the most pressing need is to reduce waste which occurs in all food system activities. Reducing waste across the whole food system will increase the amount of food available for human consumption for the given level of inputs, thereby improving input use efficiency. This is also an imperative given the economic, environmental and ethical costs this waste represents.

Further research is also needed on food system governance. This is a highly complex area due to the inherent cross-level and cross-scale nature of 21st Century food systems, involving multiple actors and stakeholders. This is further complicated by their differing understanding of scales and levels, and a range of governance approaches. ‘Adaptive’ governance may well be better suited to these complex food systems than the ‘monocentric’ governance (which is the dominating formal structure) as it accommodates the complex interactions between social and ecological systems. More importantly, however, adaptive governance focuses on the range of scales and levels inherent in food systems and notes both the importance of, and problems arising from, the cross-scale and cross-level interactions. Further governance questions relate to the location and concentration of power and role of marketing in changing consumer behaviour regarding diet and waste; and in relation to the growing environmental agenda.

The engagement of as wide a range of stakeholders as possible (e.g. researchers, policy agencies, civil society, the business community and donors) is needed in all stages of food security studies, although transaction costs can be high for all involved. The emergence in recent decades of ‘boundary organisations’ that aim to help bridge between the science endeavour and policy and other stakeholder communities has helped considerably, and boundary organisations will continue to be a key component of food security research and policy formulation.

A final point is that food security research requires an institutional setting conducive to engendering an interdisciplinary approach. A unified institutional research framework is urgently needed, and – given the growing GEC agenda – especially in relation to integrating GEC studies with other food security research. This warrants a single, multidisciplinary GEC Programme with a governance structure driven by societal-level questions of the day (e.g. food security). Failure to establish a such a framework risks holding back the enhanced interdisciplinary research agenda and innovative stakeholder partnerships needed to develop a novel way of producing scientific knowledge, the so called ‘Mode 2 research’. The summary presented here, together with the Papers and discussion comprising this thesis, call for a more holistic research agenda and advocate a more integrated way forward.

Samenvatting

Achtergrond

Voedsel is een elementaire menselijke behoefte en het realiseren van voedselzekerheid is van het allergrootste belang voor de samenleving. Om de toenemende behoefte aan voedsel te vervullen is er grote wetenschappelijke en technische vooruitgang geboekt. Ondanks deze enorme vooruitgang om de beschikbaarheid van voedsel per hoofd van de bevolking sterker te laten stijgen dan de groei van de bevolking, blijkt dat niet voldoende om allen van voldoende voedsel te voorzien: in 2010 werden circa 1 miljard mensen geconfronteerd met onvoldoende voedselzekerheid. Productie is op zich niet voldoende, er zijn meerdere factoren van belang.

Voedselzekerheid is een na te streven toestand. Eerdere definities van voedselzekerheid benadrukken de voedselproductie, tegenwoordig is de definitie die op de Wereld Voedsel Top in 1996 werd aangenomen algemeen geaccepteerd: "voedselzekerheid is gerealiseerd als alle mensen op alle momenten, fysiek en economisch toegang hebben tot voldoende, veilig en voedzaam voedsel om hun behoefte en voedselvoorkeuren te dekken ten behoeve van een actief en gezond leven". De nadruk veranderde van voedselproductie naar de toegankelijkheid tot voedsel voor allen.

Voedselzekerheid heeft snel op de politieke, maatschappelijke en wetenschappelijke agenda een hogere prioriteit gekregen als gevolg van de toenemende behoefte: 50% meer voedsel is nodig in 2030 en mogelijk 100% meer vlees in 2050. Een groot deel van de discussie over voedselzekerheid wordt nog steeds gedomineerd door de voedselproductie, doch voedselzekerheid vraagt een veel bredere benadering, waar vanzelfsprekend productie een grote rol speelt. De voedselprijspieken van 2007-2008 ondersteunden de noodzaak tot economische toegang tot voedsel, die is in feite belangrijker dan de beschikbaarheid van voedsel. Ondertussen is het inmiddels ook duidelijk dat klimaatverandering ook de gewasgroei in verschillende delen van de wereld beïnvloeden waarbij de effecten het meest ingrijpend zijn in ontwikkelingslanden. Nieuwe concepten, gereedschappen en benaderingen zijn duidelijk nodig om de brede voedselzekerheidsagenda aan te pakken. De ontwikkeling van die instrumenten is des te meer urgent vanwege de aanvullende complicaties die "global environmental change" (GEC) brengen voor degenen die nu al leiden aan voedsel onzekerheid. Om het complexe karakter van voedselzekerheid goed aan te kunnen is een interdisciplinaire benadering vereist waarin sociale wetenschappen zoals economie en de geesteswetenschappen een kritische rol spelen naast de biofysische wetenschappen.

In de negentiger jaren verscheen een internationaal GEC onderzoeksproject, Global Environmental Change and Food Systems (GECAFS, 2001-2011). Het doel van GECAFS was "strategieën vast te stellen om de impact van globale omgevingsveranderingen na te gaan en de gevolgen voor omgeving en socio-economische eigenschappen vast te stellen als resultaat van aanpassingen t.b.v. voedselzekerheid".

GECAFS plannenmakerij stelde vast dat onderzoek om dit uitdagende doel te realiseren dient plaats te vinden in de context van voedselsystemen en dus niet alleen landbouwsystemen. Daartoe dienen de verschillende elementen van de voedselketen te worden geïntegreerd, van ploeg tot bord, met inbegrip van productie, oogsten, opslag/bewaring, bewerking, verdeling en consumptie. Die gevolgen van de activiteiten moeten tot uiting komen in de goed omschreven componenten van voedselzekerheid, voedsel beschikbaarheid, toegang tot voedsel, voedsel benutting, welke alle stabiel in de tijd moeten zijn.

GECAFS' onderzoek resulteerde in het GECAFS voedselsysteem concept. Voorts bleek dat veel voedselzekerheidsonderzoek zich enerzijds op het globale niveau, anderzijds op het microniveau richt. In het GECAFS onderzoek wordt de omgevings- en socio-economische stuwende factoren en uitkomsten op regionaal niveau met name geadresseerd. Meerdere actoren fungeren op dit regionale niveau waarvan de effecten op vele schalen en niveaus hun invloed uitoefenen.

Vraagstelling en hoofdtukken in het proefschrift

Tegen de boven omschreven achtergrond worden in dit proefschrift drie vragen geadresseerd:

1. *Wat zijn de essentiële karakteristieken van een onderzoeksagenda om voedselzekerheid te adresseren*

2. *Waarom is onderzoek op regionaal niveau belangrijk*

3. *Wie dient te worden betrokken in de ontwikkeling van het onderzoek en hoe kunnen die het best worden ingeschakeld.*

Deze vragen worden aangepakt in een zestal papers die in recente jaren zijn verschenen en als hoofdstukken in dit proefschrift zijn opgenomen. Daarin worden de hoofdelementen beschreven om innovaties en effectief voedselzekerheidsonderzoek voor de toekomst te bevorderen.

De eerste van drie publicaties beschrijft de ontwikkeling van een meer geïntegreerde benadering voor voedselzekerheidsonderzoek. De eerste paper introduceert de notie van voedselvoorziening en interacties met de omgeving. In de tweede paper wordt uiteengezet hoe klimaatverandering de gewassystemen beïnvloedt en benadrukt het belang van de ruimtelijke schaal en de positie van gewasproductie in de bredere context van voedselzekerheid. In de derde paper wordt het GECAFS voedselsysteem concept geïntroduceerd waarbij gedifferentieerd wordt tussen Activiteiten en Uitkomsten. In die paper wordt een aantal voorbeelden van de voedselsysteem benadering geïntroduceerd en getoond hoe, waar en waarom de voedselsystemen benadering behulpzaam is bij het begrijpen en inkaderen van voedsel (on)zekerheidsonderzoek.

De tweede serie van 3 papers gaat in op het voorbeeld van onderzoek op regionaal niveau en de betrokkenheid van de verschillende partijen. In paper 4, de eerste van de tweede serie, wordt beargumenteerd waarom het regionale niveau zo belangrijk is voor voedselsystemen en voedselzekerheid onderzoek. Er wordt beargumenteerd waarom van lokaal naar regionaal niveau moet worden gewerkt en de hele reeks van schaal en niveau interacties worden besproken. Uitdagingen voor het overbruggen van niveaus worden besproken.

In de 5e paper/publicatie wordt besproken welke betrokkenen moeten worden ingeschakeld bij het GEC-voedselzekerheidsdebat en er wordt nagegaan welke elementen van goede praktijkvoorbeelden kunnen worden benut. In de laatste, 6e paper/publicatie uit deze reeks, wordt de theorie vertaald naar praktijk op regionaal niveau. De wijze van identificatie van deelnemers aan de discussie en de ontwikkeling van netwerken en de aanname van methoden worden besproken. De uitdagingen voor methoden ontwikkeling worden besproken evenals de internationale betrokkenheid.

Reflectie en conclusies

De essentiële karakteristieken van een onderzoeksagenda voor voedselzekerheid omvat verschillende componenten.

In de eerste plaats zal vanuit een voedselsystemen benadering moeten worden gewerkt, daarmee worden activiteiten en uitkomsten geïntegreerd (toegang tot voedsel, voedsel beschikbaarheid en voedselbenutting). In de tweede plaats zijn inter- en transdisciplinaire benaderingen vereist om de complexe interacties tussen de vele disciplinaire inzichten samen te brengen. In de derde plaats de notie van spatio-temporale interacties en verschillende jurisdicties bij verschillende schaalniveaus moeten worden bekeken en benut bij de formulering van geëigende onderzoeksvragen. Onderzoek op regionaal niveau is veel minder prominent dan dat op globaal of lokaal niveau. Effectieve implementatie van zulke opties op regionaal niveau vraagt goed omschreven interacties tussen de verschillende betrokkenen. Het begrijpen van die interacties is cruciaal in voedselzekerheid. Onderzoek in het algemeen, maar onderzoek gericht op het verbinden van schaalniveaus zijn doorgaans lastig omdat de noodzakelijke basisinformatie ontbreekt. Daarom is identificatie van de betrokkenen uiterst belangrijk. Participatieve onderzoekmethoden zoals consultaties, overzichten en scenario's zijn daarbij behulpzaam.

Het in kaart brengen van voedselzekerheidsonderzoek op regionaal niveau levert interessante onderzoeksvragen op, vooral die welke betrekking hebben op beleidsagenda's en het beheer van natuurlijke hulpbronnen. Voorbeelden hebben betrekking op intraregionale handel in voedsel of bestuurlijke problemen rond het beheer van regionale waterbronnen en het beheer en behoud van biodiversiteit. Het doen van voedselzekerheidsonderzoek op regionaal niveau is uiterst belangrijk omdat veel aanpassingsmogelijkheden zich op dit niveau voordoen, bijvoorbeeld op het gebied van logistiek en het in stand houden van regionale voorraden. Voedselsystemen omvatten vaak kritische interacties op een reeks van schaalniveaus met ieder hun eigen groep van betrokkenen en belanghebbenden. Het stimuleren en onderhouden van een goede dialoog is essentieel in voedselzekerheidsonderzoek. Bij de planning van onderzoek moet daar uitdrukkelijk rekening mee worden gehouden, verschillende methodieken moeten daarbij worden benut. Een krachtig hulpmiddel daarbij is het inzetten van participatieve scenario studies.

Het belang van schaal en niveaus dient beter te worden onderkend. Integratie van schaal en niveau zijn essentieel voor de onderzoeksagenda, inzicht in het functioneren daarvan is zeer nuttig bij eventuele interventies. De gevolgen of uitkomsten van interventies kunnen tegenvallen indien een van de volgende drie eigenschappen die interacties tussen schaal en niveaus kenmerken: onwetendheid, niet passend, gebrek aan eenduidigheid.

In aanvulling op de noodzaak van bijdrages uit verschillende disciplines bewerkstelligt de systeembenadering een intensieve discussie over voedselzekerheid. Het plaatst de voedselsystemen activiteiten in een raamwerk van sociale, politieke, economische, historische en milieukundige contexten. Daarmee wordt de vraag "wat doen we" expliciet gemaakt in al die contexten, en de vraag "wat krijgen we ervoor" wordt dan beantwoord, daar we weten welk onderdeel gevoelig is voor welke stress. Dit is voor het beleid van groot belang omdat de gevolgen (impact) in kaart kunnen worden gebracht en vaak nog belangrijker de niet bedoelde gevolgen van een bepaalde technische of beleidsmatige interventie van te voren kan worden ingeschat.

De notie van voedselsystemen ecologie is gebaseerd op lessen geleerd in de productie ecologie, de agro-ecologie en de antropo-ecologie. Het inzicht in de wijze waarop gewassen functioneren en voedsel kan worden geproduceerd, heeft geleid tot de productie ecologie en het bredere concept agro-ecologie. In de productie-ecologie wordt op basis van kennis van en inzicht in het functioneren van agro-ecosystemen zodanig geoptimaliseerd dat met minimale inzet van hulpmiddelen per eenheid product een zo goed mogelijk resultaat wordt gerealiseerd. Bij de agro-ecologie worden ook doelen van natuurbeheer of biodiversiteit, waarvoor agrarische activiteiten noodzakelijk zijn, betrokken. De agro-ecologie is daarmee gericht op meerdere doelen. Een aantal mogelijke combinaties van gewas, gewas – bodem, gewas – bodem – ziekten en plagen, zijn gemodelleerd om tot inzicht te komen over potentieel, bereikbaar en actueel productieniveau. Interdisciplinariteit en verschillende schaalniveaus zijn daarbij essentieel. De bredere benadering die door productie ecologie en agro-ecologie mogelijk zijn geworden hebben het debat over voedselzekerheid naar een hoger plan getild.

Terwijl productie ecologie en agro-ecologie concepten ver boven de voedselproductie op lokaal niveau zijn gekomen tot voedsel beschikbaarheid op hogere niveaus is voor voedselzekerheid een bredere benadering nodig. Bijvoorbeeld betaalbaarheid, verdeling, culturele normen, preferenties en de sociale en culturele functies van voedsel dienen te worden geadresseerd. Daarvoor zijn aanvullende analyses nodig over de gevolgen van menselijke activiteiten als een keten van activiteiten waarin het ecosysteem en het humane sociale systeem zijn betrokken. Dat is het gebied van de antropo ecologie, waarin andere concepten worden toegepaste en andere uitkomsten mogen worden verwacht. Dat wordt veroorzaakt door de relaties en interacties van de actoren met hun omgeving. Die relaties omvatten

1. Sleutel interacties binnen de biofysische sfeer, de socio-economische sfeer en de interacties tussen beide sferen,
2. Een hoge graad van complexiteit van relaties,
3. Meerdere schaal en integratieniveaus,
4. Een grote diversiteit aan activiteiten en actoren.

De integratieve concepten van productie-ecologie, agro-ecologie en humane ecologie tezamen met de concepten van voedselsystemen en schalen leiden tot het concept van “Voedsel systemen ecologie”.

Voedselzekerheidsonderzoek, gebaseerd op deze “voedsel systemen ecologie” is behulpzaam bij het identificeren van prioriteiten voor investeringen in onderzoek. Twee gebieden hebben speciale aandacht nodig: verbeteren van het gebruik van input benuttingsefficiëntie binnen het voedselsysteem en het verbeteren van het bestuur en beheer van voedsel systemen.

De meeste aandacht voor het verbeteren van de input benuttingsefficiëntie is gericht op stikstof-, water- en energie- en benuttingsefficiëntie in de landbouw. Andere zeer noodzakelijke onderzoeksactiviteiten betreffen de betere koppeling van plant en dier componenten in de landbouw systemen. Het gebruik van energie en water dient ook te worden geoptimaliseerd in transport en bewaring (met name de koude keten), in verwerking/bewerking van voedsel, in de detailhandel en in de consumptie. De productie ecologische benadering kan worden toegepast op het niveau van gewassen, gewassystemen, boeren systemen en op het niveau van landgebruik. Optimalisatie op ieder van die niveaus kan aanleiding geven tot andere keuzes op het laagste niveau omdat de te realiseren efficiënties op hogere niveaus veel meer mogelijk maken.

De verhoging van de efficiëntie in de productieketen valt bijna in het niets vergeleken bij de winst die is te boeken door de hoeveelheid afval te verminderen. De vermindering van afval in alle schakels van de keten is het omvangrijkst in de laagste schakels en daar is dus veel winst te boeken. Daarmee kunnen economische, omgeving en ethische voordelen worden behaald.

Er is vooral veel onderzoek nodig over het beheer van voedselsystemen. Dit is een zeer complex gebied als gevolg van de vele actoren die er in betrokken zijn en het grote aantal belanghebbenden. Die complexiteit wordt nog vergroot door de schaal en integratieniveaus.

Adaptief beheer is in die gevallen geschikter dan de eenduidige autoritaire beheerstructuur (de nu dominante beheersstructuur) omdat dat de afstemming van sociale en ecologische systemen vergemakkelijkt. Nog belangrijker is het vermogen van dergelijke adaptieve structuren om verschillende schaal en integratieniveaus snel te verbinden. Verdere vragen op het gebied van beheer hebben betrekking op de locatie en concentratie van macht en de rol van marketing en veranderend consumentengedrag ten aanzien van dieet en verspilling mede in relatie tot de groeiende omgevingsagenda.

De betrokkenheid van een groot aantal categorieën groepen van geïnteresseerden en belanghebbenden (bijvoorbeeld onderzoekers, beleidsinstanties, de maatschappelijke organisaties, het bedrijfsleven en financiers) is vereist in alle fases van dergelijke studies. Dat kan de transactiekosten voor alle partijen verhogen, maar door de verschijning van meer intermediaire organisaties worden die kosten verminderd en de kloof tussen beleid en wetenschap geslecht. Die organisaties spelen daarmee een sleutelrol bij de formulering van de onderzoeks- en de beleidsagenda.

Een laatste punt betreft de noodzaak om t.b.v. voedselzekerheidsonderzoek de juiste institutionele organisaties te hebben.. De behoefte aan een verenigend institutioneel raamwerk wordt vooral gevoeld bij de integratie van GEC studies met ander voedselzekerheidsonderzoek. Dat is een pleidooi en rechtvaardiging voor één multidisciplinair GEC programma met een beheers- en beleidsstructuur die wordt bepaald door de vragen uit de samenleving. Indien er niet zo’n structuur komt, zal dit de ontwikkeling en implementatie van een interdisciplinaire onderzoeksagenda afremmen en de mogelijkheden om nieuwe kennis volgens “Mode 2 research” afremmen.

Deze samenvatting, ondersteund door de papers die in dit proefschrift zijn opgenomen, vragen om een meer holistische onderzoeksagenda en bepleiten een meer geïntegreerde weg voorwaarts.

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Curriculum Vitae

Following a BSc in chemistry from King's College, University of London (1979) and a MSc in soil chemistry from the University of Reading (1980), John Ingram gained extensive experience in the 1980s working in East and Southern Africa, and South Asia in agriculture, forestry and agroecology research projects. In 1991 he was recruited by the UK's Natural Environment Research Council (NERC) to help organise, coordinate and synthesise research on global change and agroecology as part of International Geosphere-Biosphere Programme, launching and running a series of international research networks on crops, soils, and pests and diseases. In 2001 he was appointed Executive Officer for the Earth System Science Partnership's Joint Project "Global Environmental Change and Food Systems" (GECAFS). On the close of GECAFS in 2011, he assumed a new role as 'NERC Food Security Leader'.

John has had substantial interaction with a number of international organisations, especially the UN-FAO and the CGIAR and has worked closely with international and national departments, agencies and NGOs helping to establish region-wide research on the links between food security and environmental stress in the Indo-Gangetic Plains of south Asia, southern Africa, the Caribbean and Europe. He has published on a wide range of topics ranging from soil organic matter dynamics to food security issues. His recent activities have included promoting, coordinating and integrating international research related to the interactions between global environmental change and food security, as researched through analysis of food systems.

John is based in the Environmental Change Institute, University of Oxford.

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