Conceptualizing Food Systems for Global Environmental Change Research

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Conceptualizing food systems for global environmental change research

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Abstract

This paper outlines a framework for studying the multiple interactions of broadly defined food systems with global environmental change and evaluating the major societal outcomes affected by these interactions: food security, ecosystem services and social welfare. In building the framework the paper explores and synthesizes disparate literature on food systems food security and global environmental change, bridging social science and natural science perspectives. This collected evidence justifies a representation of food systems, which can be used to identify key processes and determinants of food security in a given place or time, particularly the impacts of environmental change. It also enables analysis of the feedbacks from food system outcomes to drivers of environmental and social change, as well as tradeoffs among the food system outcomes themselves. In food systems these tradeoffs are often between different scales or levels of decision-making or management, so solutions to manage them must be context-specific. With sufficient empirical evidence, the framework could be used to build a database of typologies of food system interactions useful for different management or analytical purposes.

Keywords: Food security; Ecosystem services; Tradeoffs

1. Introduction

Food security, defined as 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* (*World Food Summit,* 1996), is a policy issue of importance in just about every country. The food security status of any group can be considered as the principal outcome of food systems, if these systems are defined broadly and generically. Increases in the efficiency and productivity of food systems have resulted in successes around the world in reducing the prevalence of hunger and improving nutrition. However, these successes are shadowed by serious concerns about those aspects of food systems that pose threats to social, economic and environmental goals and hence undermine food security. In addition, global environmental change, in the context of social, political and economic changes, may bring unprecedented stresses to bear on food systems and food security.

Food systems have usually been conceived of as a set of activities ranging from production through to consumption. However, food security is a complex issue with multiple environmental, social, political and economic determinants. It encompasses components of availability, access and utilization. A comprehensive and holistic analysis of how the current organization of food production, processing, distribution and consumption contributes to food security requires broadening the concept of a "food system" beyond only those activities. A host of other economic, social, and environmental drivers affect food security as well, and the interactions among these drivers, activities and outcomes are complex. A broader definition of food systems therefore includes:

- the interactions between and within biogeophysical and human environments, which determine a set of activities;
- the activities themselves (from production through to consumption);
- outcomes of the activities (contributions to food security, environmental security, and social welfare) and

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- other determinants of food security (stemming in part from the interactions in bullet one).

Both food systems and food security in the 21st century are fundamentally characterized by social and economic change, such as the marked intensification of food production, the tremendous growth of processing and packaging of food products, corporate concentration in retailing and distribution, and the rising influence of large numbers of urban consumers. Developing policy to ensure food security is a tremendous challenge that requires a comprehensive and integrated analytical approach (Maxwell and Slater, 2003).

Adding to the social and economic trends are concerns about global environmental change and food systems, given the pace at which environmental change drivers are acting and the scale of human domination of ecosystems (Vitousek et al., 1997; Steffen et al., 2003). Global environmental and socio-economic changes are happening simultaneously, and they involve rapid and complex processes with uncertain consequences. So-called "cross-scale" interactions, between processes and actors in different arenas and at different levels, e.g. from local to regional, introduce even greater complexity and uncertainty (Cash et al., 2006). Understanding how to manage food systems in this context poses considerable research and policy-making challenges. Further complicating the issue is the impact that food systems themselves have on the environment, as the activities and outcomes are also drivers of global environmental change and create feedback loops.

2. Purpose of the paper: a framework for research

This paper outlines a framework for studying the interactions of food systems with global environmental change and evaluating the major societal outcomes affected by these interactions: food security, ecosystem services, and social welfare. This analysis will hopefully inform possible adaptive strategies and build adaptive capacity to bolster the resilience of food systems in the face of global environmental change. In building the framework, the paper explores and synthesizes the disparate literatures on food systems, food security, and global environmental change, bridging social science and natural science perspectives.

The outline of the paper is as follows. I first briefly review the trends that have affected both food systems and food security in recent decades. I then discuss why a "systems approach" is useful for analyzing global environmental change and food security. The remainder of the paper goes into detail on the proposed conceptual framework, which attempts to integrate food system activities with their multiple outcomes and feedbacks to drivers of change. I conclude with a discussion of research priorities to help implement and improve the framework.

3. Challenges of modern food systems

The wide ranging literature on "food systems" reveals multiple perspectives and world views (Sobal et al., 1998). The most useful conceptualizations are those which describe a food system as a chain of activities from production ('the field) to consumption ('the table'), with particular emphasis on processing and marketing and the multiple transformations of food that these entail (Heller and Keoleian, 2003; Dixon, 1999; Cannon, 2002; Lang and Heasman, 2004). The general global trends in modern food systems are well documented and are summarized in Table 1. This illustrates the multiple actors involved in food systems, the broad array of environment and social interactions encompassed in food systems, and the multiple policy challenges posed.

In the area of production of raw materials for food, the major trends of the past few decades have been identified by Maxwell and Slater (2003); Kennedy et al. (2004), and Lang and Heasman (2004) as intensification of agriculture accompanied by a concentration in the control of agricultural inputs, and a trend to larger farm sizes with hired labour globally, accompanied by increasing fragmentation among marginalized small

Table 1
Comparing some features of "traditional" and "modern" food systems

Food system feature	"Traditional" food systems	"Modern" food systems
Principal employment in food sector	In food production	In food processing, packaging and retail
Supply chain	Short, local	Long with many food miles and nodes
Food production system	Diverse, varied productivity	Few crops predominate; intensive, high inputs
Typical farm	Family-based, small to moderate	Industrial, large
Typical food consumed	Basic staples	Processed food with a brand name; more animal products
Purchased food bought from	Small, local shop or market	Large supermarket chain
Nutritional concern	Under-nutrition	Chronic dietary diseases
Main source of national food shocks	Poor rains; production shocks	International price and trade problems
Main source of household food shocks	Poor rains; production shocks	Income shocks leading to food poverty
Major environmental concerns	Soil degradation, land clearing	Nutrient loading, chemical runoff, water demand, greenhouse gas emissions
Influential scale	Local to national	National to global

Source: adapted from Maxwell and Slater (2003).

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holders. The environmental concerns over these trends are increased demands on water availability for irrigation (Molden and Fraiture, 2004), an increase in pollution from agricultural inputs and soil loss (Pretty et al., 2005), and a large increase in the energy demands throughout the food production sectors (Matson et al., 1997).

There has been a huge increase in "value-added" activities arising in the area of processing and packaging of raw materials into food products. Farming is no longer the dominant economic activity in the overall food system. As these activities have increased, corporate concentration up and down the food supply chain (vertical integration) has as well (Boehlji et al., 1999; Hendrickson and Heffernan, 2002).

The third area of activities is distribution and retail, the networks for which have greatly expanded as markets have globalized and transportation routes have improved and extended. Food now travels very long distances (Pretty et al., 2005) and the role and number of supermarkets is rapidly increasing, with considerable vertical and horizontal concentration among the major owners (Reardon et al., 2002; Lang and Heasman, 2004), a trend for the retail sector as a whole.

Fourth, there have been significant changes in how food is consumed. Overall growth in incomes has caused a world-wide dietary transition to more meat (with a concomitant rise in demand for grain production), dairy, sugars and oils. Consequently nutrition concerns relate to malnutrition in some places and obesity in others, as there is inequitable distribution of the quality as well as quantity of food, and negative consequences arise from multiple eating patterns (Popkin, 2004). This is exacerbated by the growth of urban populations who rely almost completely on purchasing food (Kennedy et al., 2004).

4. Trends in global food security

Most often food security is analyzed in terms of why people do not have it—i.e. why they are hungry or malnourished. Society still faces a number and range of food insecure situations, but the nature of food insecurity shifted fundamentally over the 20th century. Social causes are now recognized as fundamentally important (Devereux, 2000). Growth in incomes and agricultural productivity, improvements in market functioning, along with political will to intervene to prevent famines, has improved food security for many in Asia and Latin America, although there are still local and regional distributional inequities (Corral et al., 2000). Throughout Sub-Saharan Africa food insecurity persists. While the impacts of natural hazards or stresses such as droughts may trigger a crisis, long term economic factors such as market failures and poverty contribute, along with political instability and institutional weakness, and conflicts play a large role (Devereux and Maxwell, 2001).

4.1. *Food security analysis: from availability to access and utilization*

Methodologically, the analytical literature explaining food security has evolved since the late 1970s from a focus on national food production and stocks (or the supply of food), which emphasized available food supply at aggregate levels, to a more nuanced and individual-focused approach, which emphasizes access to food along with consumption patterns and preferences (Maxwell, 2001).

Amartya Sen (1981; Dreze and Sen, 1989) is universally credited with establishing the importance of access to food, as opposed to only availability, as critical to food security. Access is determined by how well people can convert their various financial, political, and other assets into food, whether produced or purchased. This insight explains inequity in food distribution and allocation, based upon income, political and social power. The tremendous growth of urban areas has also spurred a view of food security that emphasizes access and incomes, as more and more people do not grow their own food (Ruel et al., 1998).

The public health emphasis on nutritional outcomes has further amplified the food security framework by adding utilization. This highlights the influence of age, health and disease on how the human body utilizes food and its needs for different nutrients, calories and protein (Young, 2001; World Bank, 2006; Pelletier, 2002). Utilization is affected by poor hygiene, food preferences and the physiological condition affecting food absorption, as is the case for persons infected with HIV/AIDS (Haddad and Gillespie, 2001). In addition, the impact of contaminated food on health and nutritional outcomes is increasingly recognized (World Bank, 2006). Furthermore, modern food processing has resulted in less healthy foods which, although increasingly popular, contain fats, added chemicals, and high levels of salt and sugar (Popkin, 2004). With this interest in the health outcomes of food, food security becomes a concept that applies to a multitude of consumers in wealthier countries.

4.2. *Beyond food security to livelihoods*

Insights from the livelihoods approach to poverty and vulnerability have further altered views on food security. The most important point is recognizing that households have multiple objectives beyond achieving and maintaining food security (Swift and Hamilton, 2001), so they may go hungry but preserve other household assets. Secondly, in many places agriculture is not the primary income generator for rural households, and often people buffer themselves against food and income failures by diversifying out of agricultural production on their own farms (Ellis, 2000; Bryceson, 2000). Third, the natural resource base is an asset on which people depend for their survival, just like financial, social or physical assets. The environment does more than just produce food for people; it is also a source of income and a buffer against a variety of biophysical and social or economic shocks (Scoones, 1998). A fourth important contribution is recognizing that institutions at multiple levels either constrain or foster household livelihood strategies, and thus food security outcomes, often unintentionally (Swift and Hamilton, 2001).

In conclusion, the pressing issues pertaining to food security today have to do with food systems, encompassing a range of economic and environmental and social features that are undergoing rapid change (Maxwell and Slater, 2003; Lang and Heasman, 2004). Some of the major factors differentiating "traditional" from "modern" food systems are summarized in Table 1. On the supply side, raw food materials undergo many transformations and travel long distances before they reach retail markets. Although food insecurity persists in critical areas, globally dietary concerns focus less on under-nutrition and more on obesity and food safety. Income is a primary determinant of consumption and food security status, and distributional inequities are important. Food security is a dynamic condition, which results from the interplay of multiple factors. In addition, both consumers and producers are embedded in food systems in which national and international factors play increasingly important roles relative to local factors.

5. Global environmental change and food system performance

Global environmental change encompasses changes in the biogeophysical environment, which may be due to natural processes and/or human activities. These changes may manifest at the global scale or they may occur locally but be so widespread that they are a global phenomenon (GECAFS, 2005). Examples include changes in atmospheric composition from the release of greenhouse gases and the consequences such as increased temperatures (Walker and Steffen, 1997), and variability in precipitation cycles due to the ENSO phenomenon and other regional patterns (Conway et al., 2005). Food systems also contribute to global environmental change, and future trends such as increased demand for food with increases in incomes and populations will have consequences for global environmental change processes.

An important notion in global environmental change research is that changes in key drivers will affect the services that any given ecosystem can then provide, both for its own maintenance and for services such as food provisioning that contribute directly to human well-being (DeFries et al., 2004; Millennium Ecosystem, 2003). For example, mangroves may be cut down to make way for fish farms. While this enhances the food provisioning service of the coastal ecosystem, it removes other ecosystem services that mangroves provide such as flood control and breeding grounds for native fish species. Another key notion is that of feedbacks—when a process interacts with a system component and the response then produces another reaction. Feedbacks can reinforce or counterbalance the original process.

With respect to food production, recent studies (Geist et al., 2005; Wood et al., 2000, 2005) agree that land use modification for food production has significant and widespread impacts on ecosystem functioning. Much of this impact, including feedbacks, has been negative, e.g. biodiversity losses have been recorded from land conversion, and water availability and access have been heavily modified for agricultural use (Wood et al., 2005; DeFries et al., 2005). However, most studies of the impact of global environmental change, particularly climate change, have only looked at the potential consequences for crop production, e.g. Fischer et al. (2002). The interactions of the other components of food systems with environmental change remain largely unexamined. As discussed above, food security outcomes are determined by many other factors besides production.

6. The value of a "systems" approach for applied research

There is a tradition in both the social and biophysical sciences of using the concept of a *system* to help in addressing complex problems with multi-causality resulting from interactions among interdependent components. A system of interest can be assessed in the broader context or environment in which it is found, and the impact of changes in these broader environments can be considered at the scale of analysis (Aronson, 1996). Systems approaches help in understanding the critical factors that lead to particular outcomes or the interactions that govern a specific behavior of interest.

The understanding of a food system elaborated in this paper lends itself to a "systems" approach as described by Ison et al. (1997), in that it is a "problem-determined system" rather than a "system-determined problem". In developing the idea of food systems as complex, heterogeneous over space and time and replete with non-linear feedbacks, my intention is be fully inter-disciplinary, aiming for marriage of natural and social science akin to that suggested by Scoones (1999). Norgaard (1984) first described agricultural systems as co-evolved social and ecological systems. Berkes and Folke (1998), Folke et al. (2003) and Holling (2001) describe coupled social–ecological systems as co-evolved, with mutually dependent and interacting social and ecological components and highly uncertain and unpredictable outcomes. This conceptualization of human–environment interactions is useful for food systems, although the links between the social and environmental components may be indirect in many cases.

In the notion of systems as used above, I do not mean to imply that every outcome in the world is governed by macro-level or structural features. Individual actors affect change through their agency or maintain certain institutions by their actions. In complex systems there is an interplay between structure, which is usually at a broader or macro-level, and agency, which is local or micro-level

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(Clark, 1998). Thus although institutions and structures govern people's actions, the structures are also modified over time as a result of individual actions (Leach et al., 1999). This evolution in thinking allows for the recognition of heterogeneity among households, communities, and institutions themselves.

7. A food systems framework for global environmental change research

To take a holistic approach to understanding global environmental change and food system interactions, I propose a broad framework for food systems, which includes feedbacks and interactions among drivers and considers multiple outcomes (see Fig. 1a). This approach inherently accepts that ecosystems are managed (directly and indirectly) for human benefit and that one set of services may be emphasized (e.g. food production) at the cost of another (e.g. clean water for fish) and that these goals may be in conflict. It adopts the idea behind adaptive management that an appropriate conceptual framework will lead to better decisions in the face of uncertainty and unpredictable outcomes (Holling and Meffe, 1996). The normative goals of the framework are food security and sustainable environmental management.

The framework in Fig. 1 includes the major activities and actors involved in food systems, as well as the critical processes and factors influencing the social and environmental outcomes that are also part of a food system. It links these so as to explain the nature of the outcomes at a point in time or space. This builds upon the idea that within complex systems it is possible to identify key processes and determinants that influence outcomes, although these outcomes may be contested.

A central notion is that the primary outcome of any generic food system is food security, although in specific contexts food security may not be achieved because actors have multiple objectives, or there are market and other institutional failures, etc. How well food systems fulfill the objective of providing food security is open to interpretation and remains a contested and highly politicized topic (McMichael, 2007). The framework also incorporates food system outcomes that affect the natural resource base and that contribute to other social capitals or securities such as income, employment, and health. For example, income could enter the system either as a driver or as one outcome of food system activities for those who devote labor or financial capital to them (see Fig. 1a). Outcomes may be indirect or unintentional. A key research question is how an environmental change will interact with the system, and what impact it will have on outcomes.

A brief description of the framework follows.

7.1. *The food system activities*

The food system activities are grouped into four categories: producing food, processing and packaging food, distributing and retailing food, and consuming food. The first three categories constitute the food supply chain.

Producing food includes all activities involved in the production of raw food materials. These range from the process of obtaining inputs such as land and labor, breeding animals, planting crops or obtaining young animal stock, caring for the growing food material and then harvesting or slaughtering it. A variety of factors determine these activities, from climate conditions to land tenure, input prices, agricultural technology and government subsidy provisions intended to protect or promote production.

Processing and packaging food includes the various transformations that raw food material (vegetable, fruit, animal) undergoes before it is sent to the retail market for sale. All of these activities "add value" to the raw material in an economic sense, but these activities may also significantly alter the appearance, storage life, nutritional value, and content of the raw materials. For example, wheat undergoes extensive processing and packaging before it becomes bread. The determinants of these activities are quite different from those pertaining to producing food.

Distributing and retailing food includes all activities involved in moving the food from one place to another and marketing it. Distributing is heavily influenced by transportation infrastructure, trade regulations, government transfer programs, and storage requirements. Retailing is influenced by how markets are organized and where they are located, advertising, and any niche or premium category the product may fit in to.

Consuming food involves everything from deciding what to select through to preparing, eating and digesting food. Prices are influential, as are income levels, cultural traditions or preferences, social values, education and health status. As diets globalize and the food system globalizes, advertising and the structure of the food supply chain also have a large influence on what people choose to eat.

7.2. *The food system outcomes and their determinants*

7.2.1. *Food security*

The outcomes contributing to food security are highlighted in detail in the framework in Fig. 1b. The three major components of food security are access, availability and utilization. Although very influenced by food system activities, other drivers determine these outcomes as well. Food security can be analyzed for any unit, from an individual to a nation. Food *availability* refers to the amount, type and quality of food a unit has at its disposal to consume. *Access* to food refers to the ability of a unit to obtain access to the type, quality, and quantity of food it requires. Food *utilization* refers to individual or household capacity to consume and benefit from food. Each of these can be further broken down as follows.

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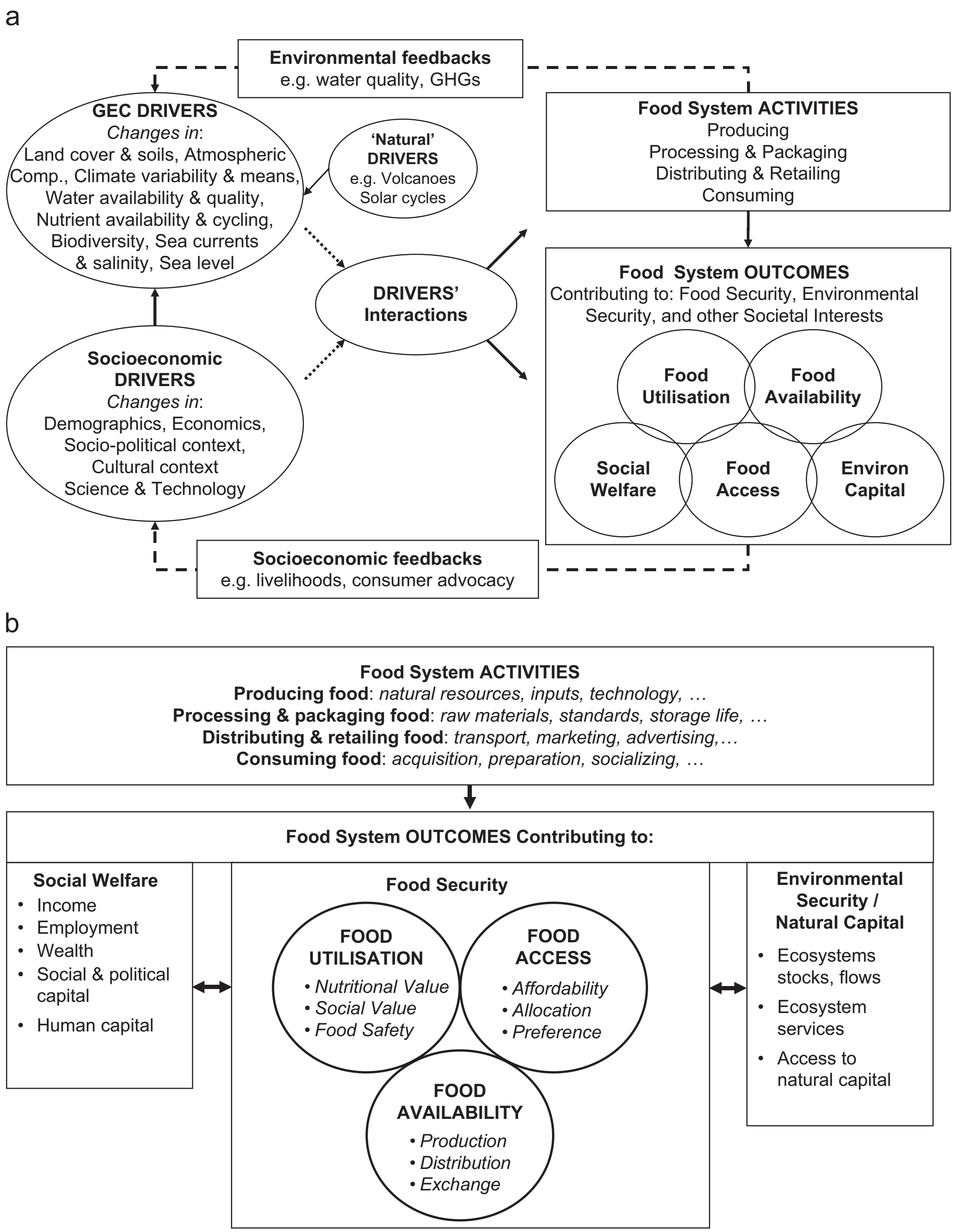

Fig. 1. (a) Food systems and their drivers. (b) Components of food systems.

7.2.2. Food availability

Three elements—production, distribution, and exchange—contribute to food availability. Although familiar terms for food security analysts, their meaning has been modified slightly to fit the agenda of describing a food system holistically.

- *Production*: how much and which types of food consumed (by a given unit) are available through local production. The determinants of availability from local production include land holding sizes, resource tenancy arrangements, economic returns to labor, human capital, and the control local producers have over their own products.
- *Distribution*: how food for consumption is physically moved to be available, in what form, when and to whom. The determinants of distribution include transportation and infrastructure, public safety nets, storage

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facilities, governance, security, and the enforcement of trade barriers and borders.

- *Exchange*: how much of the food available to a unit is obtained through exchange mechanisms such as barter, trade, purchase, or loans rather than local production. Determinants of exchange include income levels and purchasing power, informal social arrangements for barter, local customs for giving and receiving gifts, migration, gender and age structure, markets, terms of trade, currency value, and subsidies.

7.2.3. Access to food

Three elements describe accessibility of food: affordability, allocation, and preference.

- *Affordability*: the purchasing power of households or communities relative to the price of food. The determinants of affordability include pricing policies and mechanisms, seasonal and geographical variations in price, local prices relative to external prices, the form in which households are paid, income, and wealth levels.
- *Allocation*: the mechanisms governing when, where, and how food can be accessed by consumers. Markets are a key determinant of food allocation; government policies often are designed to correct market failures by allocating food to remote areas or at lower prices. Social capital influences informal allocation processes (e.g., within households), while at a broader scale social and political capital in urban areas influence where supermarkets are located. Both social and political capital influence rules for fishing, hunting, and gathering in rural communities.
- *Preference*: social or cultural norms and values that influence consumer demand for certain types of food. Determinants may be religion, season, advertising, preparation requirements, human capital, tastes, customs, and female labor force participation.

7.2.4. Utilization

The three elements of food utilization are nutritional value, social value, and food safety.

- *Nutritional value*: how much of the daily requirements of calories, vitamins, protein, and micronutrients are provided by the food consumed. Both over- and under-nutrition are issues. Determinants of nutritional value include diversity of food consumed, type of primary protein, disease incidence (which affects food absorption), education, facilities for cooking and preparing food, access to clean water and hygiene practices.
- *Social value*: all of the social and cultural aspects of consumption, for example, eating meals together may be an important part of kinship, it may be important to always have food for guests, or special foods may be an integral part of important holidays. In some places eating locally or organically produced food is highly valued. Understanding the determinants of social value requires insight into the community and household relations, as well as cultural customs.
- *Food safety*: this encompasses the dangers introduced from the addition of chemicals during production, processing and packaging, and food-borne diseases such as salmonella and CJD. The main determinants of this are the procedures and standards and regulations (or lack of) for food production, processing, and packaging.

7.3. Other food system outcomes

In addition to food security, food system activities contribute to environmental outcomes, and food security itself is determined in part by environmental factors independent of the food system activities. The conceptual framework in Fig. 1b includes not only the physical stocks of natural capital but also ecosystem services, under the heading of "environmental security/natural capital". Natural capital 'comprises the land, water and biological resources' that people use for various activities (Ellis, 2000). Ecosystem services include provisioning, regulating, supporting, and cultural services (Millennium Ecosystem, 2003).

The determinants of natural capital are largely influenced by location and geographic endowments; for example, tropical forests will have high levels of species diversity but low levels of soil carbon and nutrients, in comparison to temperate grasslands. However, both intentional and inadvertent management by people largely determines how much of that natural capital is maintained. Similarly, ecosystem services are a function of both geography and management. Thus pasture management can result in the predominance of woody shrubs rather than grassy rangelands, despite the initial or "natural" vegetation, depending upon how socio-economic factors influence management (Walker and Abel, 2002).

The framework acknowledges that access to environmental capital is as crucial to outcomes as the stock or state of the ecosystem. This access is mediated by a variety of factors (Leach et al., 1999; Young, 2002a).

Much of the food security literature stresses the importance of social and economic determinants of food security, and the framework describes these in the box entitled "social welfare". These factors are both outcomes of food system activities and determinants of food security. For those directly involved in the food supply chain, food system activities determine a significant portion of their income, wealth, social and human capital. However, for many others, income and education are determined by non-food system related activities. The framework proposed here allows for both possibilities. The framework also includes health and social capital as determinants of food security outcomes.

7.4. Linking outcomes to key determinants

The framework can be used to identify and describe the determinants of any particular outcome and relate them to

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the broader food system. An example for the determinants of access to food and availability of food is shown in Table 2. In the case of affordability, which is part of access, staple grain prices depend upon whether they are produced locally or are imported. Affordability is thus partially determined by food producing activities but is also a function of household income. In the case of allocation, most food is available in supermarkets, which is a function of how retailing is structured. However, local preferences for fish and rice are still determined by traditional cultural norms, which fall under social capital. Turning to availability of food, fish stocks are declining, which is determined by ecosystem services and their management, and local rice production is low because of poverty and low investment in agricultural technology. Thus imported rice, which must be purchased, dominates. This example illustrates the differing dimensions of food security and the need to evaluate more than just availability. It also indicates the influence of food system activities on outcomes relative to other drivers.

This food systems framework is useful for identifying entry points for changing undesirable outcomes, through an analysis of the drivers and activities that have resulted in these outcomes. In Ericksen (2007) the *vulnerability of food systems* is described as a state when food systems are disrupted and fail to deliver food security, whether this is due to an overwhelming shock, structural issues, actors in conflict, or environmental degradation. The basic goal of vulnerability analysis is to try and assign causality, albeit complex, and then develop adaptation strategies to lessen that vulnerability. Other evaluators may be more interested in the balance among environmental outcomes and food security outcomes, or that between food security and income which results from the structures and processes in a food system. Others may want to develop interventions to increase a particular outcome, such as the income that smallholder farmers receive.

8. Tracing a global environmental change through a food system

Many environmental changes have direct impacts on producing food in a given location; however, the consequences of these impacts for food security are less direct, given that food security depends upon many other factors besides availability from local production. The structure of activities and the characteristics of outcomes determine the impact of an environmental change. Thus for the example in Table 2, an environmental stress affecting local rice production might not change availability, as distribution and exchange are more important determinants than local production. The framework can also trace the consequences of feedbacks. If local farmers stopped producing rice, land use patterns would gradually change. This would in turn affect the ecosystem services of water availability and nutrient cycling. On the social welfare side, local farmers' income from agriculture would also decline. This would decrease the affordability of food, unless the farmers or other members of their households can substitute other income earning activities. These alternative income strategies may in time shift from being temporary coping strategies to principal earning strategies.

Table 2
Linkages between food security outcomes and food system activities: an example for the components of access to food and availability of food

Elements of access to food	Characteristics of food security element	Major determinants of this element	Origin of determinants of this element (cf. Fig. 1b).
Affordability	Staple grains are cheap if imported; expensive if local.	Costs of local production higher than external. Income determines how much can purchase.	Food system activity: producing. Social welfare: income.
Allocation	Most food only available in supermarkets.	Supermarket chains dominate in urban areas and local markets have been driven out of business.	Food system activity: retailing.
Preference	Fish and rice are traditional foods.	Cultural preferences and agro-ecosystem characteristics.	Social welfare: social capital. Environmental outcomes: ecosystem services.

Elements of availability of food	Characteristics of food security element	Major determinants of this element	Origin of determinants of this element (cf. Fig. 1b).
Local production	Insufficient local rice; fish is scarce.	Local rice systems are low productivity; fish stocks are declining.	Food system activity: producing; environmental outcomes: ecosystem stocks.
Exchange	Imported rice is cheap.	Open trade policy.	Food system activity: distributing and retailing.
Distribution	Imported rice is sold everywhere.	Market-driven supply system.	Food system activity: distributing and retailing.

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9. Evaluating the food system outcomes

The three categories of outcomes considered in this framework—food security, environmental security, and social welfare—are often those amongst which decision makers at different levels (household, district, nation, or region) make conscious or unconscious choices. Food systems and food security are highly contested topics, as are the conflicts between economic growth and the protection of environmental services. There are many ways in which these outcomes can be evaluated, depending upon the perspective or objectives of the evaluator, which are shaped by the political and social context. For example, rural development strategists debate the value of encouraging farmers to invest in cash crops for income generation or to concentrate on growing locally consumed staple crops. Not only are these strategies more or less suitable for different groups of farmers and communities, but they relate to different food security strategies and different environmental outcomes.

There will usually be tradeoffs among the food system outcomes in the short term, and managers and decision makers will also often be concerned with how to resolve those tradeoffs in the longer term. The pragmatic view holds that there are inevitable tradeoffs among social welfare, economic growth and environmental sustainability (Vosti and Reardon, 1997), which are heightened in the short run. The Millennium Ecosystem Assessment authors (2003) note that the increasing demand for ecosystem services adds more urgency to resolving these tradeoffs.

A stylized example of evaluating the tradeoffs in food systems is given in Fig. 2. Here the potential tradeoffs among six different food system outcomes are shown in a spider diagram, and compared between two different hypothetical systems. In the first system, local production of food is supported, resulting in high agricultural incomes but also high food prices. Greenhouse gas emissions from agriculture are higher than those from transporting food. In the second system, without the support for local food production, food prices are lower but agricultural incomes suffer. Food transport is now the major source of greenhouse gas emissions.

10. Research challenges: cross-scale and multi-level interactions

Food systems as described here are multi-level with respect to both time and space. They also span more than one analytical scale. Hence their analysis must trace cross-scale interactions, especially the feedbacks. The scale and level of observation determines which of a given range of parameters is observed to be more influential on an outcome (Wilbanks and Kates, 1999), so explanations of cause and effect will vary. The scale of observation can also limit understanding of which variables are endogenous and

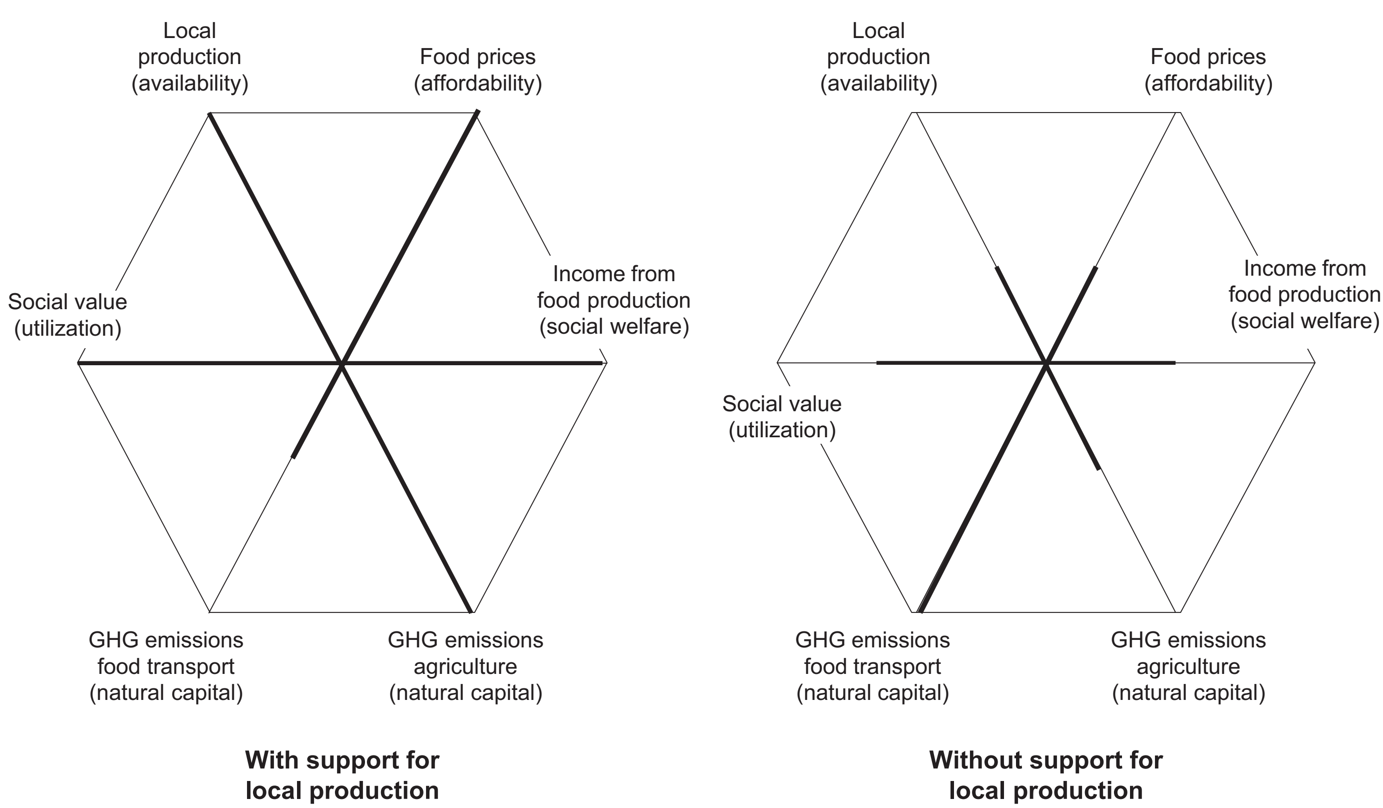

Fig. 2. Tradeoffs among example environmental outcomes (GHG emissions), social welfare outcomes (income), and food security outcomes for a given food system with and without support for local food production.

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which exogenous. Spatial scale poses a particular problem for explaining food security, as food security is best understand and evaluated at the household level. However it is governed by food system activities and other determinants, which span from the local to the global scales. Most discussions of ecological systems envision them as embedded in scale hierarchies (Holling, 2001); this is less well documented for the social side, although institutional analysts also recognize that institutions and actors are also embedded in space and time (e.g. Gibson et al., 2000; Young, 2002b; Berkes, 2002).

The diagrams in Fig. 1 are intended to be used iteratively, so one can begin or end anywhere, and the diagrams should not be interpreted as hierarchical. The diagram shows the food system at any given point in time or space. However cross-scale interactions are embedded, as the drivers, activities and outcomes interact across analytical scales such as institutional, ecological and social. Although one may choose to analyze the food system of a particular unit, one also has to consider that this level of analysis has links to higher and lower levels through drivers and feedbacks.

Perhaps more problematic is that system variability across scales results in heterogeneous outcomes, so a given pattern of outcomes will be context-specific. Any conflicts between outcomes will be difficult to resolve with only generic solutions. Policies are implemented at different levels, e.g. national, district, municipal, and understanding how policies interact either to reinforce one another or, as is more often the case, confound or act at cross-purposes to one another is important to identifying policy or decision strategies. Cross-scale interactions often introduce surprises; thus institutional analysts maintain that unless one figures out the cross-scale interactions they may result in a messy management situation (Young, 2002b). Some writers such as Cash and Moser (2000) have focused on how to get a better scale "fit" between social, political and economic management mechanisms and the ecosystem processes that are being managed. Cross-scale and cross-level subsidies are very common in food systems (Carpenter et al., 2001); for example food is imported from one location to another, across spatial scales, and increased agricultural productivity today may be at the cost of sufficient water availability in the future. Many tradeoffs involving ecosystem services are between short term gains and long term costs, for example economic growth from agricultural trade and the greenhouse gas emissions that accumulate from long distance travel of food. Another dimension is the importance of stability over time to ensuring food security (Maxwell and Smith, 1992). A diversity of sources and strategies is necessary because of the seasonal heterogeneity.

11. Conclusions for future research

With sufficient empirical evidence, this framework could be used to build a database describing typologies of food system interactions. Such a typology could be organized in several ways. One typology could distinguish between slow and fast processes in food systems. Resilience approaches to social–ecological system management suggest that managers often respond only to fast processes, even though the slow ones are more critical to ensuring a system's capacity to buffer disturbance and maintain its functions (Carpenter and Gunderson, 2001). A second typology could be organized by geographical or jurisdictional level, and describe the key drivers that are most important for determining food security outcomes at these different levels. This would be useful for developing policy or institutional interventions to improve food security. A third typology could compare the key food security and ecosystem service tradeoffs, for a series of well-described case studies that varied by geographic location and jurisdictional scale. The Millennium Ecosystem Assessment spawned global analysis of these tradeoffs, e.g. (DeFries et al., 2004; Wood et al., 2005), but this focussed primarily on food production (Zurek, 2006).

This elaboration of how to describe food systems in an integrated fashion also leads to several conclusions for future research on the consequences of global environmental change for food security. First, to understand a system holistically it is necessary to describe and analyze not only the component parts and actors, but the interactions among these parts and actors that produce variable outcomes. A goal of the system's description is thus to explain the patterns of interactions among the activities, external drivers, and the outcomes, so as to fully assess any emergent properties, as well as cause and effect. Thus, while I accept the inherent complexity of integrated food systems, I believe that a systematic approach to their analysis, through the use of case studies, can reveal critical processes and factors that govern them. However, without an adequate treatment of cross-scale interactions, the analysis will fail. The second conclusion is therefore the need to treat food systems as multi-scale and level, even if the outcomes of interest are focused at one scale in particular, for example regional. This will facilitate the identification of critical drivers and determinant outcomes as well as the evaluation of tradeoffs.

Third, as food systems are coupled social and ecological systems, institutions play a key role in mediating between the social and ecological processes and resources. This framework is intended to help the multiple managers of institutions to better understand the nature of coupled food systems. It is intended to create new knowledge that is appropriate for social learning and adaptive management. The nature of institutional processes and food system governance has not been addressed in this paper, but it is a research priority.

Fourth, this investigation has required integrating across disparate literatures, which rely on quite different methods and have different goals. For example, much of the ecological systems literature seeks to identify critical parameters, while food security literature looks for root

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causes, and food policy literature wants to identify key issues for policy resolution. I have tried to find common ground but recognize there are still some incompatibilities which may complicate analysis: most critically, the understanding of individual agency versus systemic properties in determining outcomes, and identifying the key institutions with which to work to bring about change.

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