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Assessing the vulnerability of food systems to global environmental change: a conceptual and methodological review

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Abstract: Assessing the vulnerability of broadly described food systems to global environmental change is a complex task. Although food systems are best described as coupled social- ecological systems, much of the existing literature on vulnerability focuses on either social or ecological systems alone. In addition, assessing the vulnerability of parts of a food system is not the same as assessing the overall vulnerability of the entire food system. A framework is suggested to try to integrate across a food system to assess its vulnerability, focussing on key processes and system characteristics.

Introduction

Food is central to life, and food systems have profound effects on culture, politics, societies, economies and the environment. Food systems can be comprehensively described as including the range of activities involved in every step of the food supply chain from producing food to consuming it, the actors that both participate in and benefit from those activities, and the set of food security, environmental and social welfare outcomes to which food system activities contribute (Ericksen, 2006). Interactions among external social, economic, political and environmental drivers determine how the activities are organized and carried out as well as directly influence the outcomes. Conversely, food systems themselves have impacts on the drivers, which create feedbacks over time and space.

Tremendous gains in the productivity and efficiency of food supply systems over the past decades have both reduced food insecurity and contributed to economic growth throughout the world. However, many aspects of these same supply systems are implicated in various deleterious processes that contribute both directly and indirectly to a set of processes known as global environmental change (GEC), many of which have been shown to have negative social and environmental outcomes (Steffen et al., 2003); (GECHS, 1999). GEC will itself also affect food system activities and outcomes. In addition, the way in which food supply systems contribute to economic growth is coming under question, and inequity in profits, power and distribution have increased at multiple scales (McMichael, 2000). Another issue is the vulnerability of poor people due to their lack of purchasing power and reliance in rural settings on their own unstable production. The international research community has begun to address pieces of these issues but not in an integrated or comprehensive fashion.

The concern over the negative and even harmful consequences of GEC for broadly described food systems is the particular focus of this paper. The concern is motivated by four basic narratives. First, in spite of advances made in the past century, in parts of the world chronic food insecurity persists, whether because of an overall lack of sufficient calories stemming from production failures in both crop and livestock systems in Ethiopia, nutritionally inadequate food supplies in poor urban areas of the United Kingdom, or lack of sufficient income to purchase food in Niger. Although the causes of this food insecurity are complex, projected increases in both population and consumption (Millennium Ecosystem, 2005) have led many to worry over the ability of populations to feed themselves in the coming 50 to 100 years, particularly in the absence of adequate policy responses.

Second, the past decade has heightened awareness of the increasing impact of natural hazards/ shocks on transitory food, income and environmental security: examples are the tsunami of 2004, Hurricane Katrina, and periodic catastrophic floods in various places. O'Brien (2006) argues convincingly that environmental shocks of this type are a major human security concern with which modern society has little capacity to effectively cope, given the lack of proactive policy and preparedness

Third, assessments such as the Millennium Ecosystem Assessment and the Global Environmental Outlook present convincing analyses that the ecosystem services that underpin food production systems are being undermined by a number of environmental trends such as changes in nutrient cycles, changes in hydrological cycles, changes in vegetation cover and composition, and pollution (Wood and Ehui, 2005). Adding to the concerns are model predictions that future climate change will change the spatial and temporal distribution of crop yields as temperatures rise and precipitation patterns change over the next 100 years. Efforts to resolve these problems are complicated by the uncertainty surrounding scientific understanding of GEC and its most likely impacts.

Finally, although many of improvements in human well-being have depended upon social, political and institutional improvements, these same mechanisms in many cases are inadequate to substitute for ecosystem services. Thus the decline in fisheries cannot be completely reversed with aquaculture, water management is plagued by inefficiencies and over use, and agricultural yields are stagnating in formerly high productivity areas such as the Punjab of India. Many are questioning the sustainability of industrial agriculture in ecological terms e.g. Pretty et al (2005) and Pimbert et al (2001). Furthermore, modern ecological theory suggests that a lot of ecosystem management is based upon inadequate understanding of how ecosystems really function (Holling and Meffe, 1996); (Gunderson and Holling, 2002); (Carpenter and Gunderson, 2001), and hence neither society nor many current-day ecological systems are able to handle unexpected shocks adequately, often leading to crises.

The necessity of maintaining food systems to support populations lends urgency to the scientific challenges raised. In the last decade, the notion of vulnerability has become popular to explain concerns about the potential negative consequences of global environmental change (GEC) on human well being. Vulnerability to GEC arises because of multiple stressors (e.g. market liberalization and climate variability) acting simultaneously (e.g. Leichenko and O'Brien (2002). In food insecure situations, it is rarely one event that causes people to go hungry; rather a variety of factors such as low productivity agriculture, low market prices for crops, failure of safety-net policies, and low income combine to result in food insecurity (Devereux, 2000). Misselhorn (2005) demonstrates that environmental stresses are never the only causal factor leading to food insecurity; but rather that often an environmental shock such as a drought will trigger a crisis which has longer term roots in chronically poor or politically unstable environments. Increasingly, the interactions among the multiple stresses occur in the context of unprecedented rapid change in both social and ecological systems and result in often surprising shocks to which systems must respond. Comprehensive analysis of complex systems is required to figure out how to lessen their vulnerability, in spite of the uncertainties and temporal and spatial tradeoffs. In addition, the current negative social and environmental consequences of food systems have promoted interest in ensuring that any adaptations that might be implemented to lessen the vulnerability of food systems do not result in (additional) deleterious consequences for environmental as well as social outcomes.

Purpose of the paper

This paper aims to find an appropriate policy-oriented framework for reducing the vulnerability of food systems to GEC[1]. This analytic approach frames the consequences of GEC for food systems in the context of socio-economic and political dynamics, which is recommended by Vogel and O'Brien (2004) as necessary to understand the synergistic effects of the multiple stresses that interact with food systems. This is a complicated task because food systems encompass a range of social, institutional, and ecological components (activities, actors, and outcomes), all of which may be vulnerable to GEC in different ways. A major task is to integrate the social and ecological concepts of vulnerability developed in the scientific literature so as to apply them to a food system. This intellectual effort is important because all vulnerability assessments have policy implications (Alwang et al., 2001; Vogel and O'Brien, 2004), and misguided analyses or incorrect interpretations of

[1] Of course an adequate policy-science dialogue is also necessary to ensure that scientific research has a beneficial and sustained impact on policy, but that is the topic of another paper.

results contribute to flawed policy (Walker et al., 2002). Hence analytical clarity is essential to have any policy impact.

Although a variety of disciplines can lay claim to a concern with the vulnerability of social and ecological systems to various shocks, the heightened international research interest in the topic of vulnerability to GEC, rather than the only impacts of GEC, can be traced to the findings of the IPCC Third Assessment Report (IPCC, 2001). These reports drew attention to the myriad ways in which human welfare was threatened by climate change and confirmed the importance of understanding vulnerability to GEC as a central research topic in the international research community. However, the rich and varied research that is pertinent to the subject also results in a confusing array of approaches to the topic of vulnerability. This is significantly heightened if one tries to bring together the social science and natural science conceptions of vulnerability. In the following sections, I first identify common principles in the social and ecological literature with respect to what vulnerability is and how to identify it. Then I move on to the separate streams of vulnerability analysis from the social and ecological literature, as unfortunately integration across these two approaches to date is insufficient to analyze food systems comprehensively. The third section raises questions, as I try to lay out a suitable comprehensive framework for analyzing the vulnerability of food systems to GEC.

As this paper also aims to propose a framework suitable for policy analysis, I pay particular attention to the policy implications of the different vulnerability analyses, and attempt to understand the policy implications of framing food systems as vulnerable to global environmental change, despite differences in development of these ideas in academic circles. If the goal of vulnerability assessments is to create or generate knowledge for policy intervention then the assumptions behind the research process should be carefully clarified. This is particularly true for vulnerability, as the word was used in the poverty and development literature long before the current interest in vulnerability to climate change arose; for example in the food security literature, in the hazards literature, etc. Additionally, the popularity of vulnerability as a term has led to confusion over its meaning. O'Brien et al. (2004a) contend that competing interpretations of "vulnerability" to climate change not only confuse the issue but actually lead to completely different diagnoses of the problem and hence solutions. Viewing vulnerability as the "endpoint" of adaptation to climate change gives rise to technical solutions, while viewing vulnerability as the "starting point" of adaptive capacity and adaptation leads to solutions in the institutional and social realm.

Conceptual understandings of vulnerability

Common principles in the social and ecological literature

At a minimum, most definitions of vulnerability include the idea of potential damage or adverse outcomes in relation to an external stress, a process or an event (Vogel and O'Brien, 2004). Most definitions also agree that vulnerability is more than just exposure to a shock or hazard, and that the internal characteristics of the social or ecological system (entity) can mediate or heighten the effects of a shock; this is eloquently expressed as the "double side" of vulnerability by Bohle (2001). For example, people living in the same rural community may be exposed to the same drought, but household A will not be vulnerable in the same way that household B is because of differences in income, education, and dependence upon subsistence agriculture.

As much global change research is concerned about future consequences, definitions of vulnerability to GEC often try to capture a forward looking notion, and thus the internal capacity of systems to respond to a shock and manage the harmful consequences is often expressed as *coping* or *adaptive capacity*. This suggests an ability to manage in the face of stress or adapt to future possible and uncertain changes, usually through a change in human behaviour or system functioning. These terms are used regularly in both the social and ecological literature and encompass a multitude of resources and strategies that enable systems to buffer against shocks, preventing or mitigating harmful consequences. For example, ideally post-emergency recovery programs would not just to restore what people have lost but also to strengthen their livelihood, emergency response or other systems so that they are less seriously affected by subsequent shocks (Cristoplos et al., 2004; Lautze et al., 2003).

There are at least two important implications of the internal or inherent nature of vulnerability upon which there is agreement in the different literatures. First is that history is important to understanding current vulnerability, as it will be embedded in social, political and ecological processes. For example the current vegetation state in a grazing pasture, whether grass or woody shrubs, is very much a function of the previous management practices and past precipitation patterns. Second is that vulnerability is dynamic, differential and highly contextual (and therefore scale-dependent). Thus the members of a household may be vulnerable only at certain times of the year, for example at the start of the planting season when their previous year's harvest have run out, and the women and children may be more susceptible to disease and malnutrition than the men.

Finally, as the above example illustrates, there is also consensus that vulnerability to GEC arises because of the convergence of multiple stressors, which interact as processes. Thus the negative outcomes such as food insecurity or environmental degradation which often drive vulnerability analyses in the first place, cannot be explained by a single cause. There may be multiple shocks at the same time, a trigger may lead to the collapse of a number of processes which have been slowly weakened over time or were insufficient to begin with, or a chain of sequential events may result in the overall vulnerability, which itself can be a downward and dynamic cycle. In addition, the connection between the short and long term is important but complicates the analysis.

An additional commonality is the implicit value judgement incurred in every assessment of vulnerability (H. Eakin, personal communication). In other words, some person or group (or several who may be in conflict) care about an individual, household, community, ecosystem, etc. in order to be concerned about its vulnerability in the face of a shock.

In spite of these commonalities, most of the literature on vulnerability to GEC has either focused on social outcomes or ecological outcomes. Thus a more detailed investigation of the separate streams of work will be helpful in developing an integrated framework for food systems. Because social and ecological entities are different and experience environmental change quite differently, it is dangerous to push for too much conceptual integration without first exploring the unique characteristics of vulnerability in social systems and in ecological systems.

Social vulnerability

Although ultimately, most scholars of social vulnerability are concerned with whether or not a social unit will experience an adverse outcome from a stress, there is wide variation among approaches in the details of how the term vulnerability is used and what it specifically is understood to include. Much of this variation is due to different disciplinary traditions of the authors writing on vulnerability (Alwang et al., 2001), but it has led to confusion, as there are multiple articles spelling out what vulnerability means using different language and terms (O'Brien et al., 2004a). My interpretation, intended to focus on the understandings helpful for analyzing policy issues to reduce the vulnerability of food systems to GEC, suggests that the components of social vulnerability include the following.

a. Access to assets or entitlements

Access to assets or entitlements is central to the idea that vulnerability is a social, economic and political phenomenon (Adger and Kelly, 1999), drawing upon the basic entitlement theory that Sen (1981) used to explain food insecurity. Assets range from physical through to social or political, which are often referred to as entitlements. Generally, research on household food security, the dynamics of poverty and the sustainability of different livelihood strategies has demonstrated that people with greater endowments of resources and the entitlements to use them fare better in the face of stresses and shocks. Thus livestock are a form of wealth for many households that can be sold when cash is needed. Education builds the asset of human capital, which is increasingly mentioned as necessary for livelihood diversification.

b. Coping capacity and Adaptive capacity.

Coping capacity embodies the understanding that people need more than just access to resources or assets but also active strategies to manage them in the face of risk (Barrett and Carter, 2000). Coping capacity is derived from food security and disaster management literature (Davies 1996), and is probably most meaningful if used to represent short term responses, such as selling a cow or reducing the number of meals, to ensure survival in the near future. Often people have strategies to manage risk or uncertain events. The concept of risk management is commonly used in agricultural economics literature because it is a central basis of farmer decision making in the face of everyday uncertain factors like climate variability and market price volatility. Rural livelihood diversification into off-farm activities has come to be understood as a common risk management strategy that is generally recognized as a beneficial way to increase income in unfavourable environments (Barrett et al., 2001).

The notion of adaptive capacity is meant to imply longer term changes in behaviour and livelihoods strategies, to ensure the maintenance of income or food security for the foreseeable future (Berkes and Jolly, 2001). Bohle (2001) says that the ability to take action is an important component of vulnerability. This is implied as well when (Adger and Kelly, 1999) say that vulnerability is socially constructed and requires the ability to call on resources, including institutions and networks. It implies the ability to take active steps to reorganize for better management (Eakin 2005). Although adaptive capacity is considered a key element in vulnerability, the two phrases are defined so often in relation to one another that it is confusing. Generally, adaptive capacity suggests ability to respond to shocks in the future, even though that future is unknown (O'Brien et al., 2004a). Coping capacity today may include attributes the will lead to a system’s adaptive capacity.

c. Institutional and policy framework:

Also central to the broad understanding of vulnerability as a social process is recognition of the influence of the institutional and policy context. (Adger, 1999) considers the ability to draw upon social networks central to collective vulnerability. Eakin (2005) and Leichenko and O’Brien (2004) both demonstrate that economic change or policy reform significantly alter people's abilities to respond to environmental shocks or manage climate variability, even as an every day risk. Bohle (2001) makes a stronger statement, saying that in situations of conflict and crisis, the ability to exert political control is paramount. Ellis (2003), among others, demonstrates the role of weak institutional capacity in the food insecurity crisis in Southern Africa from 2002-3 as a classic example of this. The failure of market liberalization in the agricultural sector in Southern Africa contributed to falling and stagnating farm productivity. This failure was in part due to widespread low institutional capacity in varied sectors, for example: increased market risk resulting in widely fluctuating prices, high transport costs reducing trader interest in working in remote places, and moribund agricultural and veterinary extension services. Compounding these market failures was the overall decline in public sector institutions and capacity, so the ability to respond with any safety net or other strategies was very weak.

d. Exposure to a stress, hazard or shock.

Vulnerability takes on more meaning if it is analyzed with respect to a specifically defined type of stress, otherwise it is too general (Alwang et al 2001). The concept of exposure just means that one must be exposed to a threat to be vulnerable to it. Thus people living near river banks are more vulnerable to flash floods that those living at the top of mountains because of the former group's greater exposure. Shocks or threats can differ by whether they are unusual or irregular, such as a tsunami; or chronic, repeating and regular, such as crop failures. A recent conceptual advance is that of "double exposure," or the idea that vulnerability to environmental change is bound up with other changes, especially institutional and economic. The emphasis is on the synergies between dynamic processes of change that combine to cause vulnerability. An environmental shock or stress may be the trigger that sends people into a vulnerable state, but other shocks such as a change in agricultural policy may coincide with or contribute to this. Thus the solutions to lessen vulnerability need to address these other factors as well, not only the environmental stress. By applying this to a region or country, O'Brien et al.(2004b) and Leichenko and O'Brien (2002) illustrate how vulnerability is differentially distributed and changes with time and space, as multiple factors play out.

e. Sensitivity

Sensitivity is the logical follow up to evaluating exposure. It suggests that although everyone in a place may be exposed to a stress, for example poor rains, they are not equally likely to experience its impacts some are more sensitive than others. Farmers relying on rain-fed agriculture will be more sensitive to a drought than those who have access to irrigation. Children are more sensitive to disease outbreaks than adults because of differences in their immune systems. The critical point is that sensitivity depends upon inherent characteristics of both the system and the shock to which it is exposed (Ford et al., 2006). Ellis (2003) says that sensitivity is important because little shocks may have big impacts.

Other contributions to social vulnerability

Before the current interest in "vulnerability", agricultural economists and food security analysts had developed theories about why households become food insecure --e.g. see (Ericksen, 2006). Considerable work has been done to identify food insecure populations and to develop early warning systems identifying places and people at risk of becoming food insecure. Although criticized for being overly focused on food aid relief, rather than multi-sectoral interventions, e.g. (Lautze et al., 2003), early warning and food security planning systems are maintained throughout

Africa and parts of Central America, where they are essential to donor and NGO planning. The most prominent examples are FEWS and FIVMS, run by USAID and the FAO respectively. As discussed by Maxwell (2001), current thinking on food security now recognizes that food insecurity results from three sets of entitlement failures: failure of availability (including the need for a stable supply of food), failure of access and failure of utilization. Environmental stresses are never the only reason for food insecurity (Devereaux, 2000) (Devereaux and Edwards, 2004). Misselhorn (2005) made a meta-analysis of more than 30 case studies carried out over five years in Southern Africa using the Household Food Economy framework. She demonstrates that these analyses identify multiple sources of stress, all of which contribute to food insecurity. The major drivers of food insecurity are poverty, climate and environmental stressors and conflict, along with high food prices and insufficient access to land. This is important empirical evidence of food system failure at the household level in multiple cases, and this meta-analysis documents common processes in specific situations.

The Sustainable Livelihoods (SL) approach is not that different from the other social vulnerability approaches, except that it explicitly includes natural capital as one important asset upon which people depend for their livelihoods. The SL framework has been developed and used to analyze rural development outcomes. It emphasizes both access to assets and coping strategies in the face of shocks. It offers several conceptually important ideas for analyzing the vulnerability of food systems to GEC. Lessons from the SL research are useful for their emphasis on institutions as mediating the ability of households to use their assets to manage risk. Second, the framework explicitly characterizes a vulnerability context composed of a range of risk factors or shocks, and recognizes that assets, strategies and beneficial institutional arrangements are critical to how households manage this risk and respond to situations in which they might otherwise be vulnerable. One of the most critical contributions has been to highlight the importance of diversification out of agriculture to rural livelihoods (Ellis, 2000); (Barrett et al., 2001) as both a risk management strategy but also necessary for economic growth.

In extending the SL framework to vulnerability studies, Ellis (2004) suggests that households can become vulnerable in one of several ways: the risks can increase, households can lose their ability to manage risk, or their coping capacity can deteriorate. Reid and Vogel (2006) use the framework to map out the every day or "situational" issues resource poor farmers in Kwa Zulu Natal, South Africa, face, including climate stress. They find that climate stress is not perceived as a major priority, because it the norm, and people's daily lives are constrained in a number of ways.

Eakin (2005) adopts the sustainable livelihoods framework and a "double exposure" approach. She demonstrates how the recent reforms in the Mexican agricultural sector have constrained the institutional context of production, which has in turn altered the range of risk management options farmers have to cope with or adapt to climate variability. Although climate variability poses a risk, it is not farmers' priority. She therefore recommends looking at adaptive capacity not only as the ability to directly address climate risk but also to avoid engaging in livelihood activities that may increase their vulnerability to climate shocks. Her work further supports much of the livelihoods-based research on the role of agriculture – although farmers need to engage with markets to succeed in agriculture, they also need non-farm forms of income that are protected from the many risks that agriculture entails.

Policy implications of understanding social dimensions of vulnerability:

These are considerable, as much of the research on these issues has been directed at motivating broader and more comprehensive policy responses to lessen vulnerability to global environmental change. First, the implications of vulnerability being differentially distributed within any given unit mean that one solution will not benefit all people, and furthermore as conditions change, solutions to adapt in the face of global environmental change will have to change and evolve as well (O'Brien et al 2004, Eakin 2005). Given that social vulnerability as a concept emphasizes human well-being, equity considerations are paramount. Second, the understanding of vulnerability is scale dependent: household indicators will not reveal the same issues as community or region level indicators. Prowse (2003), cites Dreze and Sen (1989)'s analysis that "a lack of vulnerability at the national, regional or community level does not preclude extreme vulnerability at the individual level". This raises complex institutional issues for targeting interventions to reduce food system vulnerability. Third, social capital, or the ability of people to depend upon a community and the social networks inherent in it, along with local institutions of reciprocity, is an important local feature for lessening vulnerability (Adger 1999). More broadly, this can be interpreted to mean that institutional and political support is an essential determinant of vulnerability, either increasing or decreasing it. Fourth is that at the local level institutions and polices must support livelihood diversification, so that access, which is often the leading constraint to food security, is assured.

In summary, as explained by (Brklacich, submitted 2005) and (Vogel and O'Brien, 2004) social vulnerability results from processes, some of which increase vulnerability and others of which enhance adaptive capacity. Only by investigating how these processes play out for a particular unit of analysis can researchers understand whether people will be more or less vulnerable to a hazard. This requires a move away from impact or outcome-based analysis.

Ecological vulnerability

Ecological vulnerability has also been approached in different ways, depending upon the background and objective of the authors. From an ecological standpoint, the idea that ecosystems are vulnerable is used to imply that they cannot withstand shocks or stresses without losing their basic ecological properties and shifting to a different state. For example, Gritti et al.(2006) discuss the vulnerability of Mediterranean Basin ecosystems to invasion by exotic species. These are classified as vulnerable if the invasion by exotic species changes the species composition so much that the ecosystem has fundamentally different properties. Hulme (2005) takes a similar approach to threats to biodiversity, as do (Christensen et al., 2004). Boughton et al (1999) define ecosystem vulnerability as “the likelihood that stressors to ecosystem will cause ecological processes and functions to vary beyond the range of natural variability,” which assumes that the appropriate historical time period over which to define natural can be defined. All these examples are primarily interested in the ecosystem itself, as a discrete entity in a describable “normal” state. Christensen et al.(2004), however, take the analysis one step further and suggest that a change in the vegetation composition of Asian steppe ecosystems could affect the people who graze their livestock on them.

There is then, a second group of authors from the ecological literature who define ecosystem vulnerability in terms of the ecosystem services upon which humans depend. To translate environmental outcomes into social implications this group of studies use the concept of ecosystem services. Ecosystem services are those that people rely upon for production, health, etc., but also those services that ecosystems themselves require to sustain themselves. They can be grouped into four categories: regulating, provisioning, supporting and cultural (Millennium Ecosystem, 2003). A simple example is from Schroter et al. (2005), who model the impact of climate change and management on ecosystem services across Europe over the next 50 years. They find that the impacts vary by type of service, differing for wood production, carbon fluxes and water stress. They also find that in some situations management has more of an impact that climatic changes.

A third approach stems from Holling's theory of adaptive cycles (Holling, 1986) which relies on the concept of resilience instead of vulnerability. Resilience is defined as the capacity to absorb change without shifting to an altered state with different properties—it is therefore often considered to be the opposite of vulnerability, or at least a positive focus rather than a negative. Resilience theory is based upon a non-equilibrium view of ecosystems which suggests that change and dynamism are the norm for ecosystems, as they continually move through adaptive cycles. Trouble arises when a system loses resilience and the system flips suddenly to a new state, which is often less desirable in terms of the ecosystem services it provides. Resilience is often lost because managers try to control these fluctuations rather than allow them to persist, or some foreign material is allowed to enter the system (Gunderson, 2003). The more resilient systems are those in which natural variation has been allowed to continue to provide diversity and renewal, so that flips do not occur. Examples have been documented in Scheffer et al., (2001) and include grassland/woodland systems, lakes, oceans, coral reefs and dryland vegetation. Eutrophication in lakes leading to turbid water is a classic example. Agricultural runoff raises the phosphorous levels in lakes, increasing algae production, which makes the water more turbid, eventually changing the whole lake ecology. It is often expensive and difficult to get the ecosystems to switch back to the desired states, as the new states (e.g. shrubby pasture, dead coral, or turbid lake water) are themselves very resilient (Carpenter et al., 2001).

Elmqvist et al. (2003) specify the role of diversity in maintaining resilience. By "response diversity" they mean that there are enough species that perform the same function, such as different grass species that can thrive in pastures or herbivores that keep coral reefs free of algae, such that the ecosystem can survive if a dominant species is threatened or eliminated. This redundancy in species is an insurance mechanism for the ecosystems and provides room for error. The ecologically-required ecosystem services can be thought of as ecosystem functions (Elmqvist et al., 2003), (Deutsch et al., 2003). Biodiversity is important because it provides an important function to allow ecosystems to continue in their current state. Lawrence et al. (2004) offer another example of this more process-oriented approach, in which they trace out the consequences of deforestation on species composition and nutrient cycling. The intensification of the agricultural cycle has decreased the natural nutrient replenishment from fallows. At a broader scale, the landscape fragmentation is decreasing biodiversity and affecting water cycles. Swift et al.(2004) draw out the scale-related implications of diversity for agricultural landscapes. In many cases, the loss of diversity at the plot scale can be substituted for by agricultural inputs and labour. At the landscape scale, however, diversity requires multiple land uses to be maintained throughout a broad area.

Coupled social-ecological or systems

The ecological focus of resilience theory has always accommodated the influence of human management, and the idea of coupled social-ecological systems was introduced in order to explicitly accommodate the social mechanisms behind ecosystem management (Berkes and Folke, 1998). The concept of coupled systems presents ecological and social processes as co-evolving and joined, not distinct and separate. In social-ecological systems, resilience has three defining characteristics:

a) The amount of change that the system can undergo while still retaining the same controls on structure and function.
b) The degree to which the system is capable of self organization
c) The system's ability to build and increase its capacity for learning and adaptation.

The first characteristic of resilience means that the system has a good deal of buffering capacity and can absorb shocks. Normally, slowly changing variables are responsible for this. Component b) means that the system can take action, including restructuring or reorganizing, to respond to its own feedbacks, which of course depends upon how well social managers understand these feedbacks. Component c), the ability to learn, means that past mistakes are incorporated into new responses and better management (Carpenter et al., 2001; Deutsch et al., 2003; Holling, 2001).

Although this theory is helpful in conceptualizing the interactions between ecological and social systems, it ultimately is concerned with the ecological outcomes, rather than the social, except in so far as the ecosystem services upon which human well-being directly depend are affected. Walker and Meyers (2004) attempt to classify the empirical evidence gathered to date which demonstrates the occurrence of "regime shifts" in social-ecological systems. There are very few cases to document in which one could say that the social system had shifted to a different state – the reorganization or shifts in strategies are too small to constitute a shift. Another group of case studies document how local communities continually adapt the management of their local ecosystems, primarily because their livelihoods depend directly upon maintaining the natural resource base (Alcorn et al., 2002; Berkes and Jolly, 2001); (Seixas and Berkes, 2003). These studies all stress the need for social and institutional mechanisms which enable close monitoring of ecological processes and flexible management regimes, in order to avoid loss of system resilience.

Policy implications

The primary implication of this notion of social-ecological systems is that the concept of adaptive management is critical for resilient systems. In adaptive management, change and fluctuations are accepted as the norm and furthermore as important for maintaining system resilience (Gunderson, 2003). Second, the management or policy implications of managing against vulnerability (or for resilience) in ecosystems suggest a focus on slow changing variables, rather than the fast or stochastic variables, as it is the former which give systems resilience. A third implication is that by focussing on resilience and adaptive capacity, rather than vulnerability, this research can be said to foster solutions, albeit complex and learning based. It places a high premium on learning about systems over time, and adapting management as new phenomena emerge. For example, to manage fish stocks adaptive management would alter the bag limits to follow the natural ebb and flow of fish breeding cycles, which would actually result in a more stable fish population (Carpenter and Gunderson, 2001). It also emphasizes allowing disturbance to enter into the system (Folke, 2002), so that the capacity to handle surprise is maintained.

This poses considerable institutional challenges to instigate a more proactive and learning-based approach to ecosystem management based upon the monitoring and interpretation of ecological information.

One question about the utility of resilience theory social systems is that it is trying to identify regime shifts, which may be too extreme a case for social systems. Ideally, policy makers would like to prevent social system collapse, particularly in the case of food systems given that their vulnerability or collapse results in food insecurity.

Other models of social/ ecological vulnerability

There are other generic approaches to looking at the social implications of ecosystem change (and vice versa) that vary in their emphasis on the social or ecological side which may be useful for food system studies.

One group of studies that examine the issues surrounding ecosystem change and the consequences for both human and ecosystem well-being stem from research into the causes and impacts of land use change. The relevance for food system studies is obvious, given that clearing land for agriculture is a dominant driver of land use change (Geist et al., 2005). Asner et al. (2005) develop a framework attempting to understand which factors make ecosystems vulnerable to degradation after land use change. Synthesizing across a number of studies, they conclude that the bioclimatic setting, the edaphic setting and the intensity of land use change are controls on the susceptibility of the natural resource base to degradation.

The policy implication of identifying land use change as resulting in altered ecosystem services is that choices have to be made about which service will be promoted at the expense of others, and whether this makes sense for long run sustainability. The MA concluded that globally, the gains in provision of food and fibre have reduced other ecosystem services such as habitat provision, freshwater supplies, and biodiversity, as well as key regulating services like nutrient cycles and controlling pest outbreaks (Table C1 Millennium Ecosystem, 2005). In the case of wild fish populations, their harvesting has been unsustainable. These trends are also echoed for the Southern African regional assessment (Biggs et al., 2004). In the long run, in both globally and regionally, there are concerns for human well-being due to the declines in ecosystem services, notably human health and localized poverty, as well as water scarcity and pollution.

Turner et al (2003a; Turner et al., 2003b) propose a comprehensive framework to combine social and ecological vulnerability. The conceptual strength of the framework is that it defines vulnerability by drawing upon the social concepts of entitlements and coping capacity, as well as the ecological concept of resilience. The differences in entitlements explain why vulnerability is differentially distributed, coping capacity is in many cases determined by structural factors, and resilience is understood to refer both to the system flexibility and the ability for social learning. Vulnerability results from interactions both within the defined system and with the external stresses, but resides in the system. Intrinsic to their analysis is the idea that neither social nor environmental change occurs alone –rather they are inter-related, and the causal chain of events/ processes matters. They emphasize the interactions of institutions and ecosystem processes together which can result in vulnerability, but allows for system feedbacks. They also try to incorporate analysis across space and time scales, which demands attention to system boundaries. Luers (2005) draws on this framework to try and quantify the important system characteristics that contribute to vulnerability for farming systems in the Yaqui Valley of Mexico. Her findings suggest that management has more impact on vulnerability than any particular stressor.

Ford et al. (2006) adopt a similar approach with a case study of how the Inuit in Arctic Bay, Canada, are vulnerable to and how they are able to adapt to the signals of climate change. They try to identify the specific system (in this case a community) characteristics that contribute to exposure/ sensitivity or (and in some cases and) adaptive capacity. Thus changing from hunting with sleds and dogs to using snow mobiles has increased sensitivity to the dangers of increased prevalence of thin ice, and a slow erosion of the traditional knowledge base among the youth is limiting their adaptive capacity to respond to the increased prevalence of thin ice.

Eakin et al.(2005) also try to identify the farming household/ system characteristics that confer both sensitivity and adaptive capacity to climate variability and market risk for diverse groups of farmers in Argentina and Mexico. In Argentina, farmers had greater adaptive capacity if they had more access to physical and material resources. In Mexico, farmer access to financial and technical assistance were key to lessening vulnerability, while higher levels of crop-dependent income and pests were linked to higher vulnerability.

The "syndromes" approach tries to explain vulnerability by broadly integrating across descriptive case studies to document global syndromes. Ludeke et al. (2004) and Petschel-Held et al.(1999) describe this approach as a process of documenting archetypical interactions between people and ecosystems. They first identify key global change trends, such as urban sprawl, soil degradation, and coastal erosion. Then they look at the different interactions among these trends and cluster them into syndromes. Using global data sets they try to document the prevalence of syndromes in different geographic regions. The "Sahel Syndrome" is one describing the interaction among impoverishment, soil erosion and agricultural intensification and expansion that leads downward spiralling cycle. "Green revolution syndrome" is another in which increasing social disparity and agricultural land degradation result from the application of mal-adapted agricultural techniques designed to increase agricultural productivity. It is suggested that syndrome analysis provide a process for identifying possible policy interventions (see Kasperson et al., 2005)).

What is meant by the vulnerability of food systems?

A general diagram to depict the components of food system vulnerability is shown in Figure 1 (Ingram and Brklacich, 2002). While this is conceptually logical, there are still unresolved issues to sort through to get at what actually makes a food system vulnerable and what this means. The framework for food systems explained in Ericksen 2006 asserts that the primary and neutral objective of these systems is food security. This suggests that when a food system is disrupted and fails to deliver food security, whether this is due to an overwhelming shock, structural issues, actors in conflict or environmental degradation/ change, it should be considered to be vulnerable. This is consistent with the suggestions from some authors that a) vulnerability is a concept that requires the imposition of human / social values and b) vulnerability (or resilience) can only be assessed if the purpose of the analysis has been determined.

However, food systems also contribute to environmental degradation and sometimes to loss of income (e.g. for agricultural workers and farmers) – these environmental and social welfare outcomes are also important to many in society. Should we consider these as indications of food system vulnerability as well, given that food systems are social and ecological systems, and global environmental change is affected by food system feedbacks to the ecosystem? Furthermore livelihood shocks can lead to food insecurity in the future. Are food systems vulnerable if they are economically or socially unsustainable?

In trying to think of food systems so broadly, I have posed a unit of analysis that is somewhat unwieldy. The broad idea of a food system was proposed in order to get at the underlying processes that contribute to vulnerability. However, there are few examples of how to evaluate food system vulnerability holistically. The social approaches discussed above only apply to parts of a food system, primarily either the actors or the outcomes. The ecological literature looks at systems, but it may be difficult to measure links between social and ecological vulnerability/ resilience because of long food chains and substitution of other inputs for degraded natural capital. Adger (2000) suggests that one can only measure ecological resilience in social systems with direct reliance on the resource base, as the loss of environmental entitlements will matter less if the system is less directly dependent upon the ecological resource. Additionally, we cannot assume that social and ecological resilience move together – they may contradict one another (K. Galvin, pers. comm).

Eakin and Luers (2006) have recently summarized the major trends in the literature on social and ecological vulnerability, and their conclusions are relevant for the task of analyzing the vulnerability of food systems. They propose that there are still four analytical challenges for assessing the vulnerability of complex social-ecological systems. First is how to address the combined effects of multiple stressors acting upon a system, as it is difficult to identify links among them or determine cause and effect. Second, uncertainty has not been dealt with adequately in any of the vulnerability assessment literature, which poses the great risk of incorrect analysis about where vulnerability lies currently and even more so for future possible vulnerability. Third is the difficulty of analyzing cross-scalar interactions, which are difficult to tease out but which may well be the source of much systemic vulnerability. Fourth, insufficient attention has been paid to equity and justice as key ingredients to prevent system vulnerability.

They outline a “roadmap” for how to address some of these deficiencies. I suggest that the following are the most relevant at this stage for analyzing food systems. First, Eakin and Luers recommend both being clear about the unit of analysis and social values that are brought to bear on why anyone is concerned about the vulnerability of this unit. Second, they say it is important to identify the harm that the system can suffer, and what harm or danger means for the system. Third, they outline a process to identify the system characteristics that contribute to exposure, sensitivity and adaptive capacity. Because systems are dynamic, they emphasize understanding the interactions among drivers and components of the system. Fourth, they recommend identifying thresholds of change and indicators.

Published studies of food system vulnerability

There is scant empirical evidence regarding the vulnerability of food systems. Although there is a rich body of information on food security outcomes, much of this is based upon household studies rather than food system studies. There are few studies that refer to the activities in a food system and how they could be vulnerable to GEC in the context of multiple stressors, with the exception of food production in agricultural and aquaculture systems, and most of that literature looks only at one or two stressors. One gap in this literature is studies on the vulnerability of economic systems (markets, trade) to GEC such as deforestation or soil degradation.

A few scholars have attempted to explain the structural (ie internal or inherent) vulnerability of modern food systems. Sundkvist et al.(2005) are motivated by the negative social and environmental consequences of food production. They hold that these negative consequences result from the current food marketing structure, which distances consumers from producers and thus inhibits the recognition of and response to feedbacks in the food supply chain. They identify four main trends responsible for this vulnerability: intensification, specialization, distancing, and concentration and homogenisation. Feedbacks within the food system can either be masked (i.e. not perceived) or disregarded (perceived but not acted upon). Often this is because the production is at a different point in space or time from consumption, but it is also because consumer knowledge of food systems has declined and there are insufficient institutional mechanisms to manage feedbacks. The solution they pose is to encourage more localized food production, to decrease the distance and better institutional management to tighten the feedback loops.

E. Fraser borrows from several theories to look at food system vulnerability (Fraser, 2003; Fraser, 2007; Fraser et al., 2005). He uses the concept of adaptive cycles from resilience theory, in which systems with high potential, tight connections and low diversity are susceptible to “collapse” and a subsequent period of reorganization. He maintains that 21st century food systems have reached this stage – industrial food production is intensive and high output, yet it relies on only a few crops. The tight connections, he argues, are evidenced by rapid transportation and the quick spread of disease and other contaminants through the system. Diversity is low because many areas rely on only a few sources of food production, rather than using multiple entitlements. To explain food insecurity he turns to entitlement theory as necessary for explaining the relationship of poverty and other factors to food insecurity. However, this illuminates contradictions between ecological vulnerability and social vulnerability. Social vulnerability as understood by entitlement theory is most commonly associated with low wealth and economic or social isolation or weak connections. This is the opposite for ecological systems as explained by resilience theory. The common feature to both is the importance of maintaining diversity so as to preserve options in a crisis.

A third view is from political economic and sociological critiques of food systems such as McMichael (2000) and Hendrickson and Heffernan (2002). These authors propose that although the corporations governing modern food systems (i.e. industrial agricultural production, factory based processing and supermarket-controlled retail) are very powerful, the systems themselves may be vulnerable. This vulnerability arises from the degree of specialization and homegenization, which can make it difficult to adjust to changes in preferences or to serve smaller markets. McMichael (forthcoming 2006) also suggests that the level of subsidization that affluent diets require in terms of energy and global markets, threatens their very sustainability. As only one quarter of the global population can afford these diets, the poor and their environments are paying too high a cost. Increasing social awareness of this inequity is further giving rise to organized social and political opposition in a debate over the future of food sovereignty.

Conclusions from the published evidence

The literature summarized above suggests the following characteristics of food systems that might lead to vulnerability in the face of a shock or stress:

- heavy reliance on external or distant resources
- low diversity in assets or entitlements

- inequity in both access to resources and ability to take action to use them or increase them
- institutional weaknesses
- inflexible policy
- lack of functioning markets and low levels of economic activity
- tight controls over highly specialized production, supply and marketing chains
  - Lack of management for change and dynamism
- Distancing of production from consumption
- Cross-scale interactions (including subsidies) which are poorly understood and lead to uncertainty and surprise
- Ignoring the slow variables and only responding to the fast triggers.

Possible methods to assess food system vulnerability

To understand system vulnerability, it is not sufficient to only address each activity or each outcome separately, as vulnerability of the system may arise from the sequencing of certain processes and the interactions between them. (Brklacich, submitted 2005) and (O'Brien et al., 2004a) stress the importance of beginning with processes, not outcomes. H. Eakin (personal communication) suggests that the sequencing among food system processes determines how signals of stresses, such as those from GEC, are “transmitted” to vulnerable consumers (the potentially food insecure population). In trying to integrate social vulnerability theory with ecological, several of the authors discussed above emphasized understanding the specific characteristics of the system which constitutes the primary unit of vulnerability analysis. In Table 1, I try to lay out five principal questions to help identify these specific characteristics:

- what in the food system is vulnerable,
- to what are they vulnerable,
- how GEC shocks are transmitted through the system,
- what causes system sensitivity, and
- finally, what is the coping or adaptive capacity of the system?

These questions of course have to be answered specifically for any given food system. However, beginning with the activities is unwieldy and overly generic. Using the food system framework described in (Ericksen, 2006) links food system outcomes back to activities. In addition, the food security outcome determinants are integrative, and I propose that their analysis leads back to the processes that gave rise the outcome in the first place.

An example is shown in Table 2, using preliminary data from South Asian food systems in drought-prone areas. In this example, the specific determinants of the components of food utilization are shown: nutritional value, social value and food safety. The specific characteristics of each determinant are a function of the food system for that site – e.g. the primary protein is lentils, which is due to a combination of factors including the production technologies available, the general climate and soil conditions, market structure, consumer access to different proteins (of income and markets) as well as their preferences. The sensitivity of lentils to decreased water availability during a drought is a function of the hazard – in this case drought – as well as the production process for lentils. However, lentils can remain a part of the diet because the strong regional market for lentils means they are readily available from other areas less affected by drought. Thus the market provides the food system with coping capacity, which in turn reduces the vulnerability of the primary protein in this diet to drought.

The process described in tables 1 and 2 also suggests an initial framework for identifying food system vulnerability syndromes. If the key characteristics that determine

a) how a GEC shock or signal is transmitted through the food system,

b) how the food system is sensitive to the GEC shock, and

c) the coping or adaptive capacity of the food system

can be systematically identified for enough food systems in specific geographic locations around the world, it should be possible to start to identify the "symptoms" of food system syndromes, and the key interactions that result in these syndromes. This could be consistent with the more quantitative work on vulnerability focused on identifying thresholds of change and modelling the interactions among stressors, attributes and outcomes identified by Eakin and Luers (2006).

Other insights and remaining questions:

Because food systems incorporate disparate components, the framework for analyzing their vulnerability will have to allow for multiple expressions with different conceptions of vulnerability. It is still not clear whether the vulnerability of one activity or one outcome means the whole system for a geographic location is vulnerable. The example from Table 2 does not address these intra-system tradeoffs. Over space and time it is likely that component vulnerabilities will be unevenly distributed, and there is a real possibility that these vulnerabilities will contradict one another. The examples from figure 2 could occur for the same food system: one component (primary protein) is resilient in a drought yet the other (dietary diversity) is vulnerable. Over time how can the system adapt to be more resilient?

At a broader scale, small scale agriculture is economically risky for farmers, yet local and diversified sources of production may offer a more “environmentally sustainable” type of agricultural system. Conversely, if farmers integrate into the international trade economy and produce crops for export, thereby earning income to purchase food and have a broader array of food entitlements, what will the implications be over the long run in terms of food provisioning? Are food systems more or less vulnerable to GEC if food is produced locally than if consumers rely on international trade?

The answer to these sorts of questions requires tools that go beyond the concepts discussed in this paper, such as scenario exercises and a framework for evaluating adaptation options. The framework outlined here has, however, outlined the basis for identifying vulnerability across broadly described food systems.

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Table 1: "Roadmap" for assessing the vulnerability of food systems to GEC

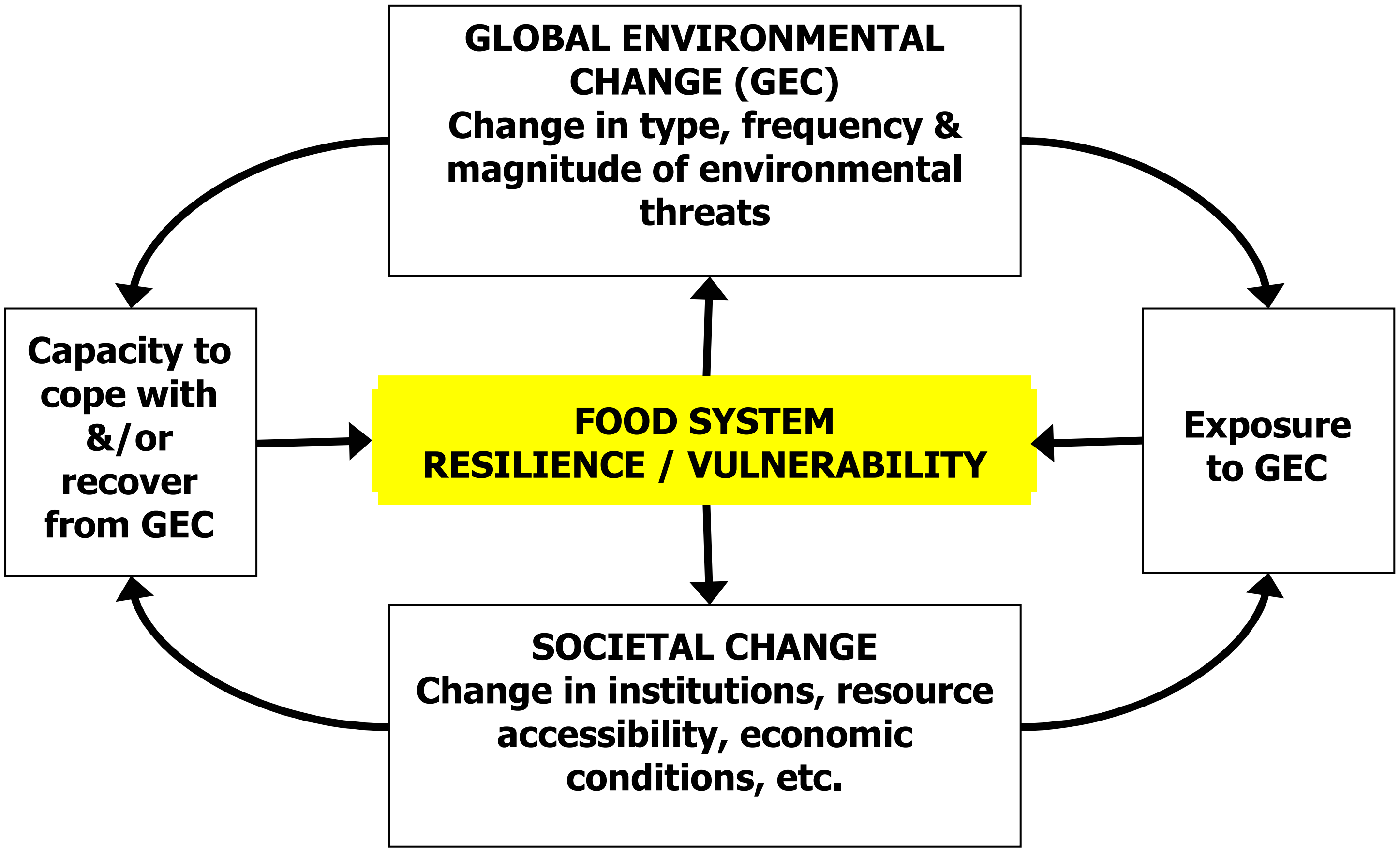
Vulnerability focus	Food system concern	Evaluation criteria
What is vulnerable?	Consumers can be food insecure. The environment can be degraded. Social welfare can be diminished.	Food security lens Biodiversity loss, nutrient cycle altered, water polluted, etc. Income lost, inequity increased, migration increased
To what are they vulnerable?	Consumers, the environment and social welfare are vulnerable to the additional stress of GEC, given the social/ institutional and economic stresses already inherent in the food system.	This pertains to who and what are her or his social values
How is a GEC shock / **signal transmitted**? (?? This determines exposure?)	Through the relevant parts of the food system	The determinants of activities or the food system outcome components
What causes system **sensitivity**?	The social, economic, etc. characteristics of the food system activities and drivers	Leads to the potential for vulnerability
What gives the system **coping capacity**?	Specific social, economic, institutional and ecological components of the system	Protects against vulnerability

Table 2: Example of the components of food system vulnerability to Water Stress

Key determinant	Determinant characteristics	Sensitivity to water availability	Coping/ adaptive capacity	Vulnerability to water availability
NUTRITIONAL VALUE				
Food diversity	Milk supplements diet of rice and lentils	Cows need four months rain to produce milk	No functioning milk market to purchase from when own production fails	**High**
Primary protein	Lentils	Lentils need two months rain	Lentil market functions so can always buy them	**Low**
SOCIAL VALUE				
Community celebrations & cohesion	Special foods for key celebrations, e.g. onset of monsoon	Increased variability of monsoon disrupts and diminishes role of celebrations	Significance of celebration foods declines leading to reduced social cohesion	**Medium**
Kinship / Etiquette	Luxury foods (e.g. eggs) for guests	NA	NA	NA
FOOD SAFETY				
Contamination from pesticides	Farmers use more chemicals in irrigated areas	Chemical use increases when irrigation increases	Consumers are slowly becoming aware of the dangers from pesticides	**Medium**

Source: unpublished data from GECAFS IGP regional project.

Figure 1: Generic framework to evaluate system vulnerability



Source: Ingram and Brklacich, 2002.

Figure 2: Example of contrasting food system vulnerabilty