Food system resilience

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Food System Resilience: Concepts, Issues, and Challenges

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Abstract

Food system resilience has multiple dimensions. We draw on food system and resilience concepts and review resilience framings of different communities. We present four questions to frame food system resilience (Resilience of what? Resilience to what? Resilience from whose perspective? Resilience for how long?) and three approaches to enhancing resilience (robustness, recovery, and reorientation—the three "Rs"). We focus on enhancing resilience of food system outcomes and argue this will require food system actors adapting their activities, noting that activities do not change spontaneously but in response to a change in drivers: an opportunity or a threat. However, operationalizing resilience enhancement involves normative choices and will result in decisions having to be negotiated about trade-offs among food system outcomes for different stakeholders. New approaches to including different food system actors' perceptions and goals are needed to build food systems that are better positioned to address challenges of the future.

Contents

1. INTRODUCTION

How we produce, process, transport, retail, and consume food has evolved for millennia in a complex web of interactions across many actors within each country and across the globe. Thus, food systems today are seen as complex social-ecological systems (SES) (1) operating across multiple levels on spatial, temporal, and jurisdictional scales (2–4). Their actors are driven by multiple driving forces, and food systems result in numerous important outcomes, ranging from food and nutrition security to environmental, economic, and social impacts (5). Their complexity makes food systems vulnerable to a wide array of shocks and stresses (6), which can individually or interactively impact single or multiple points across the system, with the COVID-19 pandemic laying bare many of the pinch points in the system (7).

Many food system conceptual models have been developed for a range of research and/or planning purposes (8) and are now being increasingly applied to studies of food system resilience (9, 10). Despite this attention to food system resilience, few studies have provided proper dimensions or case-study examples beyond the efforts of defining resilience. This is particularly important when applying resilience concepts to food systems frameworks for developing practical options to enhance the resilience of a food system, and this has led to a key question: What do we want to make more resilient? Is it the food system functioning (i.e., the way the system operates) or is it the food system function (i.e., the outcomes)? If the latter, how do we balance the resilience of positive outcomes such as food security, employment, and social capital against negative outcomes? These include overexploiting natural resources, pollution, habitat degradation and greenhouse gas emissions (11), diet-related and increased zoonotic diseases, and other negative socioeconomic impacts such as the loss of traditional skills, knowledge, institutions, and farming practices, modern slavery, and loss of cultural heritage (12). How do we agree which positive outcomes should be the function of our food systems, and hence made more resilient? How do we balance the relative importance of such positive outcomes in driving policy decisions (e.g., should nutrition trump job creation objectives)? Increased interest in food system resilience has brought together food system and resilience concepts. In this article, we investigate how different concepts of resilience can be applied to developing strategies for enhancing food system resilience. We propose a "three-Rs" (robustness, recovery, reorientation) approach to food system resilience, rooted in an understanding of food system risks, shocks, and stresses (13). We build our narratives and reflections on the basis of recent work developed by 13 research projects that comprise the Resilience of the UK Food System in a Global Context program (14) but also integrate experiences of resilience research across the globe.

Reorientation: rejecting the food system outcomes status quo by accepting alternative food system outcomes

2. FOOD SYSTEMS CONCEPTS

The food systems concept has emerged over recent years as a key way to address food security challenges (9, 15–18). Food systems include the range of activities related to producing, processing, distributing, retailing, preparing, and consuming food. These activities are undertaken by a wide range of people (actors) whose activities are influenced by a range of governance and social, policy,

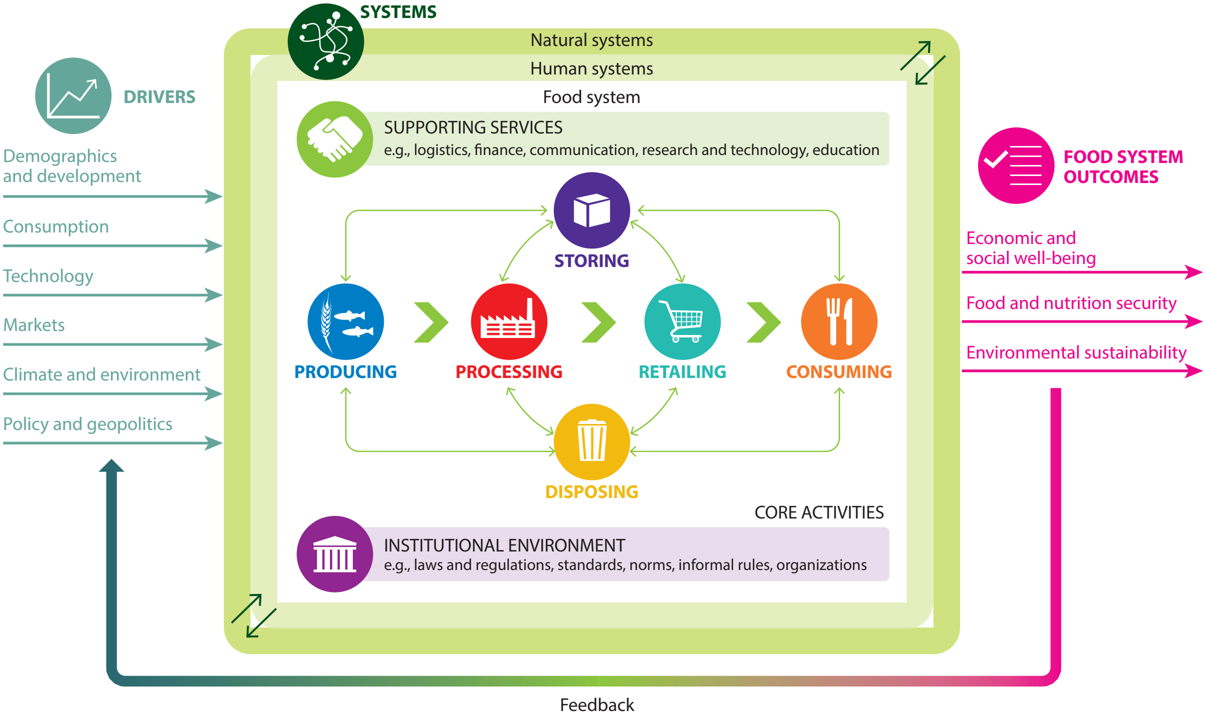

Figure 1

A food system: actors, their activities and relationships, what drives them, the food system outcomes, and feedback loops. Data from Foresight4Food (**http://www.Foresight4Food.net**).

technological, market, environmental, and economic drivers, including stresses and shocks. The actors' activities result in a wide range of social, economic, and environmental outcomes (16, 19).

Outcomes do not spontaneously change; they do so as a result of the actors changing their activities. Similarly, actors do not spontaneously change their activities; they do so in response to a change in a driver(s) to either capitalize on an opportunity or mitigate the impact of a threat. So to change a food system outcome (i.e., transform it from state A to state B), the actors need to adapt their activities, which means changing either the external system drivers or the internal system drivers (i.e., the relationships between actors). A targeted change in any food system activity (e.g., adapting diets), undertaken to transform a given outcome (e.g., poor health to better health), will, however, have repercussions across the whole system, thereby affecting nontarget socioeconomic and environmental outcomes. Trade-offs (and often unforeseen consequences) inevitably exist; any transformation of outcome will feed back to the drivers (see **Figure 1**).

Food system actors may, however, have normative goals that align with, or diverge from, outcomes that are socially, economically, or environmentally sustainable and just (20, 21). Therefore, one of the key discussions when considering building food system resilience is how to deal with complex and uncertain feedbacks and trade-offs across the different food system outcomes, and different perceptions of the desirability of those outcomes among different actors. This requires a pluralist approach and mechanisms to visualize and assess trade-offs across food system actors to achieve given food system outcomes at multiple levels across spatial, temporal, and jurisdictional scales (22).

Interactions between actors and drivers clearly determine the actors' activities, and hence how the food system operates (i.e., its functioning; the "what we do"), and therefore the outcomes (i.e., its functions; the "what we get") (23). Nevertheless, from a systems perspective, the key issue is that an overall activity (e.g., farming, processing, retailing) occurs as an integral part of the system, rather than how it occurs in fine detail. In other words, does it matter if the activity is undertaken by a few "large" actors or many "small" actors as long as it happens? Clearly, there are major social and economic considerations given the massive contribution food system activities play in livelihoods, enterprises, and national economies. For instance, in the United Kingdom, approximately 95% of food system enterprises are classed as "small and medium," with an annual turnover of £25 billion and employing more than 110,000 people (24).

That food system dynamics result from the activities of people (i.e., food systems actors) underpins the notion that food systems can be seen as SES (25, 26). As a systems approach, SES focuses on interactions. It is, however, critiqued by both systems theorists and social scientists, who have drawn attention to deep-seated epistemological difficulties with the term and highlighted the danger of overlooking issues of power and agency (13, 27, 28). For instance, Helfgott (13) noted that development theory and practice has a long history of wrestling with issues of power and empowerment (e.g., what constitutes improvement, who gets to decide this, for whom and how?). Other authors noted that social resilience requires that people have the power and freedom to mobilize their assets, flexibility, social organization, learning, and sociocognitive capacities to actively shape their future (29).

3. FOOD SYSTEM SHOCKS, STRESSES, AND RISKS

Food systems are vulnerable to a range of interacting shocks and stresses (6, 30). Both can have a major impact on key food system outcomes such as providing adequate quantities of good quality food at affordable prices, meaningful livelihoods, and environmental sustainability (31). Both can influence change either directly or indirectly.

Shocks are abrupt events of differing probability of occurrence and severity of impact, and may even be wholly unimagined: a surprise (32). Analysis of a half-century of drivers of shocks for both land- and marine-based food systems around the world identified extreme weather events, geopolitical events, financial market crashes, and short-term cost spiraling of fertilizer and other inputs, disease outbreaks, and conflict as major shocks (33), often compounded by policy change and mismanagement. Food safety scares can also significantly "shock" the system (34). The impacts of a combination of shocks, such as extreme weather and disease outbreak, can be particularly significant, as exemplified in the sidebar titled Interacting Shocks to Banana Production in Colombia.

Compared with shocks, food system stresses are longer-term drivers or conditions that are more easily perceived. Examples of stresses include gradual changes in landscape-level land use and agrochemical use, dietary shifts, climate change, demographic change, regulatory alterations, trends in commodity prices, and functional biodiversity loss (35–39).

Biodiversity loss is of particular concern, as the functioning of food systems is deeply rooted in the environment and is highly dependent on multiple ecosystem services provided by biodiversity (39, 40). Food production directly benefits from a range of vital ecosystems services. These include natural pest regulation estimated to contribute US$906 billion p.a. (41); soil-based services such as decomposition, nutrient retention, and nutrient cycling; and nitrogen-fixation by microorganisms estimated to be 140–170 million tons of N p.a., valued at approximately US$90 billion p.a. (42). Pollinators also provide valuable services and shocks and stresses affecting pollinators, such as unseasonal weather, pollution, and disease, can have significant impacts on food systems (43, 44).

INTERACTING SHOCKS TO BANANA PRODUCTION IN COLOMBIA

Colombia is a major supplier of bananas to Europe and the United States, and Colombian banana production faces serious climatic, biological, and economic pressures, which will also influence the resilience of food systems in importing countries. Productivity has declined more than expected in recent decades, perhaps due to lack of investment in production systems. Also, the industry will require major investment to avoid climate change impacts that severely threaten banana production.

The greatest biological burden to production comes from the foliar disease Black Sigatoka (138), requiring continual fungicide applications in most regions. The recent arrival of Tropical Race 4 (TR4) of Fusarium wilt in Colombia and then Peru poses an existential threat to the industry (139). The exported banana variety Cavendish is highly susceptible to this soil-borne disease. An additional side effect of recent hurricanes could be dissemination of the disease from the flooded areas of La Guajira, where the disease has so far been confined. The banana trade exemplifies a highly efficient yet vulnerable agricultural production and trade system.

The threats from climate change and numerous plant diseases have brought the industry to a juncture. Down one path is business as usual, in which a new TR4-resistant Cavendish cultivar is bred or genetically engineered (140). This would allow the industry to continue much as before but leave it vulnerable to the next deadly disease and ignore the issues of heavy fungicide use, compromised soil health, and continuing climate change. Alternatively, a resilience strategy could be adopted, focusing on agroecology and production diversity and increasing the sustainability of the system—or accepting less plentiful bananas. The trade-off to the resilience pathway is cost. Investment in research, adaptation to more complex production systems and supply chains, education and training, and higher wages for workers would elevate prices. Who would bear these additional costs is unclear.

Disruption in trade is also a major concern, particularly for nations relaying on food imports (see the sidebar titled The United Kingdom's Reliance on Food Imports), and interruptions to supply chains can be particularly significant for cities dependent on local logistics (45). Although some complex network analysis tools exist for given commodities (46), tools to systematically identify boarded food system vulnerabilities are currently scant and need to be developed.

THE UNITED KINGDOM'S RELIANCE ON FOOD IMPORTS

The United Kingdom's reliance on food imports has been steadily rising, with almost half (48%) of consumption now satisfied through imported food (83). The reliance of the UK food system on imports has emerged from the current trade agreements between the United Kingdom and its many trading partners. Disruptions to these trade policies, either directly between the United Kingdom and its partners or their side effects elsewhere, are important stressors of which to take account. COVID-19 disruption to global seafood trade has also showcased how quickly and dramatically global interdependence effects can be felt; the United Kingdom saw massive shifts in export/import markets result in an 11% decline in seafood imports volume and price per kilogram up 2% in the first half of 2020, while exports plummeted 23% and price per kilogram declined 12%, presenting a significant challenge to businesses.

A large proportion of fresh foods and meat are imported via the Dover Strait network. The business objective of maintaining low stock levels, especially for short shelf-life products, based on just-in-time supply chain strategies, relies on the Dover Strait and Channel Tunnel routes. Roll-On-Roll-Off ferry services between Dover and Calais and Dover and Dunkerque, and the Channel Tunnel's Freight Shuttle services between Folkestone and Calais, are the country's most significant arteries for the movement of food imports carried in accompanied road trailers. This therefore represents something close to a single point of failure in the UK food distribution network.

Shocks and stresses may interact and can influence or precipitate each other to lasting effect. For example, a shock such as an extremely wet or dry growing season that decreases harvests could be amplified by a stress such as increasing soil compaction, which in turn may stimulate a long-lasting stress among farmers who find it difficult to financially recover from the income loss. However, not all actors in a food system will experience a shock or stress in the same way or to the same degree—some may benefit, whereas others may struggle (20, 37). The impact of shocks and stresses might be severe or minor, depending in part on how much of the system they affect, what this means for the actors and outcomes, and the actors' responses. Thus, understanding the nature of different shocks and stresses, and their reach to different parts of the food system, is a first building block for understanding food system resilience (47).

Adaptation: changing the way food system activities are undertaken to transform their outcomes

Furthermore, one needs to understand the risk of a particular shock or stress, including (but not limited to) unknown events, and hence explore uncertainty (48). Fan et al. (30) refer to risks as decision-making situations in which the likelihoods of potential outcomes are known to the decision-maker (whereas in uncertain situations, they are not). Risks can vary in detectability, the likelihood of an adverse current or future occurrence, and the severity of their impact (49). They can be examined through, for example, foresight and scenario analysis (48). However, risk perception is often heavily dependent on contextual factors (50). Hazards that provoke a particular sense of dread, are unfairly distributed, or are unmitigable may prompt heightened risk perceptions (50, 51). Social processes may amplify risk perception through media (52), which can produce a knock-on effect, such as the panic buying witnessed during the COVID-19 pandemic (53, 54).

A recent review of current risks to the food system highlights the climate crisis, natural resources depletion and degradation, biodiversity loss, emerging diseases and food safety scares, trade shocks and conflict, and political instability and also points to their various interactions that can results in cascading risks leading to perfect storms (30). For example, a sharp inflation in the price of staple food was among the contributory factors of the uprisings and social unrest that culminated in the Arab Spring (55); protests often led to domestic revolutions and had heavy socioeconomic repercussions for the majority of Middle East and North African countries (56).

Shocks, stresses, and risks are intertwined with the concept of vulnerability. Similar to the concept of resilience, vulnerability has not received a consistent definition and interpretation, being often related to exposure, sensitivity, coping, adaptation, and connected concepts (57). Here, we envisage food system vulnerability as linked to the risk of a system being exposed to adverse events and falling into vicious loops that jeopardize food security and other desirable food system outcomes. This interpretation shows multiple interlinkages with resilience, sustainability, security, and justice (58). Major questions to address food system shocks and stresses relate to the likelihood, severity, spatial and temporal extent, detectability, and perception of food system risks and who (e.g., individuals, communities, governments, or businesses) is perceived to be responsible for addressing different risks. Food system risks can be considered on two axes, from high–low likelihood and high–low impact, which also include unknowns and other unquantifiable elements due to data gaps. This means that any understanding of food system resilience is a reflexive function of how the risks are parameterized: which risks, shocks, stresses, and actors are included or excluded, and at what levels on temporal, spatial, and jurisdictional scales (2).

4. LINKING CONCEPTS OF RESILIENCE AND FOOD SYSTEMS

4.1. Resilience Concepts as Used by Different Communities

The concept of resilience has been developed and framed by different disciplines including, inter alia, ecology, social sciences, and engineering. Its application in a food system context is still relatively new despite the term gaining considerable traction in the agriculture and food community.

Holling (59) coined the now common ecological systems definition of resilience as a measure of the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables. This equates to our concept of the functioning of the system. Thresholds are central to this definition of resilience. Severe perturbations can potentially trigger numerous reactions across spatial or temporal scales that can bring the system over a threshold, causing it to shift to a new state. Similarly, small shifts in system functioning, which are not visible, can move system functioning toward a precipice, where additional perturbation creates a systemic change in ecosystem functioning (60). Resilience recognizes that a system can have multiple stable states and can maintain function as a result of internal reorganization, i.e., its adaptive capacity (61). Béné et al. (62) suggested three important components to consider: the abilities of a system (*a*) to absorb losses due to disturbances, (*b*) to adapt through learning and incremental adjustments, or even (*c*) to transform through radical changes in the face of stresses and shocks.

A shift of attention toward coupled SES, such as food systems, led to the suggestion that resilience may be better investigated if understood as a project of key system actors who benefit from persistence, recentering analysis on how power and authority shape system functions (63, 64). Ostrom argued for embracing complexity and developing better diagnostic methods to identify combinations of variables that affect the incentives and actions of actors under diverse governance systems (65) paving the way for polycentric governance (66, 67). Yet, the complex nature of SES means that they self-organize, and novel configurations can emerge due to nonlinear feedbacks and actor agency (68). This feature of integrated SES can make managing them a challenge, but it also creates opportunities for recovering or reorganizing following a disturbance.

Additional framings of resilience come from a variety of disciplines, such as the psychology literature, where it has been defined in its most basic sense as the process of adapting well in the face of adversity, trauma, tragedy, threats, or even significant sources of stress (69). In engineering, resilience is seen as focusing on the speed with which a system can return to an equilibrium state following disturbance (70). Supply chain resilience refers to the adaptive capability of a supply chain to prepare for and/or respond to disruptions to make a timely and cost-effective recovery, and therefore progress to a postdisruption state of operation, which should ideally be a better state than prior to the disruption (71).

Recent definitions of resilience encompass aspects of both engineering and ecological resilience, in terms of maintaining the persistence of functioning in the face of perturbations, including the potential for internal reorganization of system interrelationships to achieve this where necessary (72, 73). Finally, enhancing resilience in physical infrastructure has typically been technocentric and heavily grounded in robustness, i.e., the capacity to prevent or minimize disruptions via a risk-based approach that emphasizes control, armoring, and strengthening (e.g., raising the height of levees to protect them from flooding). However, challenges facing infrastructure are not purely technological, and ecological and social systems also warrant consideration (74).

Another concept that has been used in the resilience discourse is the notion of tipping points [often used synonymously with thresholds (75)], where a small perturbation triggers a large response. These are well recognized in complex environmental systems (76). The concept is also important in the context of food system resilience because tipping points are often difficult to predict, making them hard to manage. This was the case in the 2008 food price spike where a combination of relatively minor tipping points led to a major impact on food security. Many reasons were advanced for the ensuing food crisis, including not only poor harvests due to weather anomalies but also commodity price speculation, increased demand for grains, export bans on selected foodstuffs, inadequate grain stocks, higher oil prices, and the use of crop lands for the production of biofuels (77). Tipping points in food systems could therefore be better understood as combinations of intertwining factors (78).

The final concept for investigating food system resilience is the notion of an emergent property, central to systems thinking, which has been expressed as "the whole is more than the sum of its parts," where whole equates to emergent property (79). An overall result is that the idea of emergent property is a unifying epistemological concept (80). Other work describes systems thinking as an emergent property itself, based on four simple conceptual patterns (rules) (81): distinction (What is _ ? What is not _ ?), system (Does _ have parts?), relationship (Is _ related to _ ?) and perspective (from the perspective of _). These four concepts are crucial in applying systems thinking to food system dynamics.

4.2. Framing Food System Resilience and the Four "Qs"

Understanding food systems as SES can provide the concepts necessary to understand and model the complex system dynamics involved in the multiple interactions between human and natural components (82). Several authors have offered framings of food system dynamics drawing on the resilience concepts discussed above. One approach is to apply a resilience framework based on SES principles (26). This aims to define those factors that help achieve food security for all and also provide insights into how to maintain the system in this desirable regime. The social-ecological perspective, rooted in an appreciation of the complexity of systems, carries significant analytical potential (83). Some authors have analyzed food system resilience in relation to specific past shocks, e.g., major famines caused by specific environmental problems (84) or more current shocks, including COVID-19 (7, 85).

Irrespective of the specific context, and analogous with the three pillars of sustainability, Hertel et al. (86) argue that resilient food systems must be financially equitable (economic resilience), must be supportive of the entire community (social resilience), and must minimize harmful impacts on the natural environment (ecological resilience). Although they identify diversification as a major theme to enhance resilience, and which can occur across the entire supply chain and at different levels of organization, an important initial activity involves agreeing on a boundary for the discussion.

Helfgott (13) identified four key framing questions (the four "Qs"), answers to which help to define the boundaries of the systemic resilience sought; they point to the inclusion, exclusion, and marginalization of certain stakeholders and the issues that concern them (87).

1. **Resilience of what?** Is it the soil, the crop, the farm enterprise, the local market as an institution, food supply, or the food system more generally? We can consider the food system activities (the functioning), the outcomes of these activities (the function), or both. Although certain individuals may have a particular interest in specific activities (e.g., farmers in farming, caterers in catering), we argue that from a societal-level viewpoint, the interest lies in the resilience of the overall food system outcomes (**Figure 1**) rather than in the individual activities per se; food security is one of the four highly valued features in a society (88).
2. **Resilience to what?** We need to understand the nature of the individual shocks and stresses that affect the food system and how they may interact to amplify the overall impact. Resilience depends largely on the severity and frequency of the shock or stress to which the system is exposed. The shock or stress can be external to the food system (e.g., an extreme weather event or demographic change) or internal (e.g., a food safety outbreak or dietary change).
3. **Resilience from whose perspective?** Is it from the perspective of a given actor in the system (e.g., a farmer or a retailer) or from that of a policymaker, or company CEO, or society

at large? We need to know which features of the system need to be preserved, which can change, and what constitutes desirable change (improvement) for whom, and from whose perspective. This question is important for understanding power, justice, and equity, as well as trade-offs between food system outcomes, relative to different system actors.

4. **For what time period do we need to build resilience?** It is important to distinguish short-term interruptions due to shocks (e.g., bad weather or an IT malfunction interrupting just-in-time fresh grocery deliveries) from disruptions due to stresses that affect the longer term (e.g., changing dietary preferences, shifting cropping regions). It is also important to understand the interactions between the two and the notion of temporal mismatches (89). In the context of dynamically shifting risk environments, strategies to enhance resilience over a shorter timescale may deplete resilience over the longer term, necessitating specification of the time frame over which resilience is being considered (90). Resilience-building measures need to account for temporal dimensions.

Helfgott (13) further notes that the answers to each of these four key framing questions iteratively inform the others, and depend on who is involved in answering them and on whose behalf.

Food systems operate over a range of levels of spatial, temporal, and jurisdictional scales. This raises the potential for scale challenges, i.e., situations in which the current combination of cross-scale and cross-level interactions threatens to undermine attempts to enhance the resilience of food system outcomes (2). These challenges include ignorance (the failure to recognize important scale and level interactions in food systems altogether; e.g., distress cattle sales reduce national price), mismatch (the persistence of mismatches between levels and scales in food systems, e.g., food security responses planned at the national level versus community level), and plurality (the failure to recognize heterogeneity in food systems in the way that scales are perceived and valued by different actors, even at the same level, e.g., local food aid programs versus local social safety nets).

4.3. Resilience Concepts for Food Systems: The Three "Rs"

Tendall et al. (47) conceptualized food system resilience from a holistic perspective, as encompassing the complexity of whole food systems, including social, economic, and biophysical processes operating across many scales. This work produced a firm foundation for integrating food system and resilience thinking. Given that resilience-building concepts for food systems need to be considered in light of the answers to the four key questions discussed above, we next consider what goals actors have for resilience. Different aims for building resilience will require different actions. Most policy, practice, and societal discussions focus on enhancing resilience of the food system outcomes, with emphasis on either robustness or recovery.

Robustness is based on the ability of the food system actors to adapt their activities to resist disruptions to desired outcomes (i.e., maintenance of the status quo). Examples include using more heat-tolerant crops (91), storing water on-farm to buffer against drought (92), changing land management to ensure that there is sufficient natural habitat to support pollinators (93), and pest-eating organisms, diversifying supply chains (45), building up soil quality and nutrient reserves, and strengthening strategic food reserves.

Recovery is based on the ability of food system actors to adapt their activities to return to desired outcomes following disruption (i.e., bounce back to the status quo). The ability to recover (i.e., their resilience capacities) is what helps people restore, protect, and maintain (or, in some case, improve) their levels of well-being in the face of shocks (7). An example is the ability of supermarkets to rapidly restock following unprecedented demand (i.e., panic buying) for pantry staples by having strengthened their resilience capacity with centralized distribution systems (94).

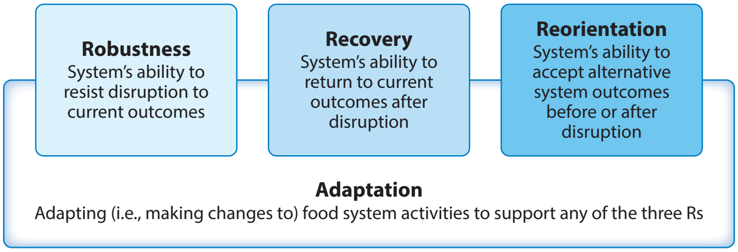

Figure 2

The three "Rs," all of which require reorganizing (i.e., adapting) food system activities.

There is, however, a third concept to enhance the resilience of the food system outcomes, reorientation. This involves accepting alternative food system outcomes before or after disruption and is based on the premise that changing societal expectations/demands of system outcomes can enhance food system resilience by making it inherently less vulnerable to shocks and stresses. But there will be trade-offs. Adapting activities so as to transform outcomes requires trade-offs to be negotiated among stakeholders, which can require considerable political and/or financial investment, and/or societal acceptance (87).

All three concepts (the three Rs; see **Figure 2**) need to be rooted in a clear understanding of food system shocks, stresses, and risks, and they all involve food system actors moderately or substantially adapting their food system activities (i.e., doing things differently). As noted above, actors will not adapt their activities without reason, but in response to a changed driver(s) to either capitalize on an opportunity or mitigate a threat. So this in turn requires changing the policy, economic, social, and/or technological drivers that influence how different food system actors undertake their respective activities; activities do not spontaneously change.

Although elements of robustness and recovery will continue to be important components of increasing food system resilience, aiming for transformed food system outcomes in the reorientation strategy might ultimately prove to be the most important resilience-enhancing mechanism. This is because this may exhibit the highest potential for structural change toward a just and lasting reduction in vulnerability to shocks and stresses. Systemic challenges may demand systemic innovations (95); as such, there is a need to shift from a focus on mere adjustments such as harm reduction and mitigation to real structural change to achieve transformed outcomes (96, 97).

The answers to the four questions (Section 4.2) and the debate about the three Rs above have major relevance to food system policy, practice, and societal attitudes, and especially for post-COVID-19 recovery pathways. Different stakeholders in the food system will have differing views about what type of resilience they envision and what actions are needed. Enabling the discussion around these questions will therefore allow for more coherent, joined up responses to the shocks and stresses the food system faces as a whole.

4.4. Adaptation and Transformation and Their Links to the Three "Rs"

There are growing calls for the need to transform the food system (98, 99). Other authors refer to incremental versus transformative change (100, 101), and adaptive versus transformative change, i.e., "to change existing practices or behaviours within existing social–ecological systems (adaptation) or enact more fundamental changes that can alter dominant social–ecological relationships and create new systems or futures (transformation)" (102, p. 823).

As it is not always clear exactly what needs to be transformed (is it the food system activities or the food system outcomes or the drivers?), we differentiate between adaptation and transformation, not by the degree of change but by what changes. We restrict the term adaptation to changing the food system activities, and the term transformation to changing the food system outcomes (see **Figure 1**). So, in essence, to transform a food system outcome from state A to state B requires food system actors to adapt their activities, which means the food system drivers need to change. A specific example is the change of phosphorus use by farmers in the United States in response to concerns about eutrophication (103). This means that to transform an outcome the drivers need to change to cause the actors to adapt their activity(s). The degree of adaptation of activity(s) will determine the degree of transformation of food system outcomes, and major transformation of outcomes will generally require major adaptation of food system activity(s).

However, for the robustness strategy, the aim is not to transform the food system outcomes but to prevent shocks and stresses disrupting the outcomes' status quo. An example is for a retailer to adapt their supply chains by diversification so shelves are always stocked if one supply line falters. For the recovery strategy, the aim is similarly not to transform the food system outcomes but to adapt food system activities after they have been disrupted by shock or stress such that they return to delivering the status quo. An example is for a farmer to adapt their seed storage facility to keep extra seed to replant in the event of poor germination. For the reorientation strategy, the aim is to reject the status quo and to accept—and move toward—transformed outcomes.

Reorientation aims for a different outcome(s), i.e., transforming an outcome from state 1 to state 2 (e.g., poor diets to healthy diets). This means adapting the food system activities to adopt a different trajectory; the relevant actor(s) needs to adapt the way they undertake their activity. On the supply side, these could comprise, for example, shifting to production methods (activities) underpinned by fundamentally different principles (104) or developing innovative supply chains. On the demand side, they could include introducing circular economy approaches to nutrient management, changing diets to less energy-intensive foods, or providing alternative proteins. In summary, adopting any of the three "R" strategies to enhance resilience of food system outcomes will require actors to adapt their activities, which will necessitate changing the drivers.

4.5. Concepts for Enhancing Food System Resilience

There are various principles for enhancing resilience of SES (of which food systems are a prime example) (105), but developing a detailed road map toward the operationalization of these involves normative choices. These include, for example, the relative value of different types of outcomes, which needs to be navigated to enable trade-offs to be managed (e.g., food price and accessibility versus environmental impact). Trade-offs between different actors with different value sets and aims need to be negotiated (87) (e.g., businesses versus citizens, citizens in one country versus those in another country, the rights and opportunities of future generations over current ones). This also makes assessing the enhancement of resilience more than a technical challenge of developing the right metrics and requires the involvement of postnormal and/or postcolonial approaches to navigate normative choices (106, 107).

Against this backdrop, approaches for enhancing the resilience of SES typically look to identify and measure common resilience characteristics (108). For example, Biggs et al. (105) identify seven key principles for building resilience at the SES level that can be applied to food systems: (*a*) maintain diversity and redundancy, (*b*) manage connectivity, (*c*) manage slow variables and feedback, (*d*) foster complex adaptive systems thinking, (*e*) encourage learning, (*f*) broaden participation, and (*g*) promote polycentric governance. These principles capture many of the concepts that contribute to resilience: adaptive cycle and panarchy, multiple system states and critical thresholds, and adaptive governance (109). The first three principles can be applied to both ecological and social systems, whereas the final four focus on the social element of managing and building resilience. Meanwhile, Oliver et al. (12) identified numerous actions by different actors (individuals, businesses, government) to facilitate food system transformation, presented as a framework of potential solutions that can be implemented across hierarchical levels of the food system. They make the point that the list is not exhaustive and multiple solutions must be implemented across all hierarchical levels in order to overcome the undesirable resilience of the current food system.

Food system transformation: transforming food system outcomes for health, environment, enterprise and equity

Food system actors might embed alternatives or new configurations of innovative practices in a way that can institutionalize fundamental changes in the structure, functions, and relations of the system. For example, COVID-19 may be considered a global crisis (initially a shock, now a stress) that may lead to substantially "changing the game" for many food system actors (104, 110, 111). Increases in household food consumption under COVID-19 restrictions (112) have challenged or stimulated the food delivery industry for both groceries and restaurants, influencing consumer shopping behavior in the short term. Its long-term impact can be facilitated by changing dietary patterns with proper marketing and policy design. Interest is also increasing in local food production and, in particular, growing food in home gardens and allotments (113, 114), with potential knock-on effects for individual's psychological resilience, health, and well-being (115). Meanwhile, innovators such as food-box start-ups and food order and delivery services might play an increasingly important role in future food systems and will contribute to resilience capacities in ways that are too early to predict.

Although answers to the four resilience questions frame the issue, addressing it calls for a new dynamic that is grounded in the power of the interactions between systems actors and other stakeholders. This new dynamic can be thought of as negotiating food systems resilience, which includes an enhanced focus on process, inclusivity, and participation. It aims for understanding key trade-offs and power dynamics, expecting iterative engagement over time and governance scales, rather than aiming for immediate consensus (87). This means it therefore needs to further consider the need to overcome lock-ins that prevent food system transformation. Sometimes referred to as undesirable or perverse resilience (116), these may need coordinated interventions implemented by different actors (e.g., individuals, businesses, government) and targeted at different types of constraint, e.g., knowledge, economic/regulatory, sociocultural, and biophysical constraints (12). They might require simultaneous interventions in both supply and demand. Novel approaches to food production and distribution can struggle to expand from marginal niches and become mainstream without such assistance, e.g., protection from competition. From a multilevel perspective, how niches become viable, gain credibility, and extend their reach helps to characterize their transition (117).

4.6. Concepts for Assessing Food System Resilience

Efforts to assess food system resilience have largely focused on the development context (118, 119) and on food security (26, 120) with limited consideration of the broader multiple components and objectives of food systems. The UN Food and Agriculture Organization (FAO) has developed an approach to resilience that measures changes to food security over multiple-year periods based on options available for households' livelihoods, e.g., access to basic services, assets, sensitivity, social safety nets, and adaptive capacity (118, 121). Measuring resilience over time against a baseline, as a function of the change in livelihood and environmental variables, acknowledges the importance of cross-level temporal dynamics. Throughout the years, this metric—most recently called Resilience Index Measurement and Analysis II in its adjusted version—has gone through a number of conceptual and methodological improvements with respect to earlier models, reaching more dynamic and robust standards. However, the FAO examples illustrate the very limited nature of approaches to considering the resilience of food systems thus far.

Although there is a growing understanding of components that contribute to resilience, efforts to measure resilience are complicated by the importance of context. This includes specific place and time and the composition and shape of the relationships between each variable (e.g., individuals and institutions). This challenges the scientific community's development of a tool by which resilience can be measured. The ability to quantify resilience would support research efforts to identify when a food system is approaching the limits of its functioning before it is too late and shifts in its function are triggered. Notable applications so far have been arising across diverse sustainability and resilience dimensions, following the need to move beyond GDP gauging and the transition toward pluralistic and holistic outlooks (122, 123). Tackling this challenge requires a multi- and interdisciplinary approach, integrating expertise from numerous disciplines and combining methods. This highlights the importance of multidimensional metrics and indexes in defining and measuring complex phenomena (124). To date there has been relatively little cross-fertilization between the different disciplines exploring resilience measurement despite their shared theoretical foundations (116, 125).

Thus, although the understanding of the underlying mechanisms of resilience has improved (72, 73), and although multivariate approaches have been tested (126), there is still the challenge of assessing resilience due to failing to consider multiple components of resilience. Thus, if we want to assess resilience levels of a food system, either qualitatively or quantitatively, key metrics need to be agreed upon. Jacobi et al. (127) proposed a first set of variables for this, using empirical evidence from Kenyan and Bolivian agricultural systems. They proposed assessing buffer capacity, self-organization, capacity for learning, and adaptation in a food system as the key variables and developed specific indicators for each variable.

Enhanced tools for understanding the diverse dimensions and interpretations of food system resilience are increasingly needed for better defining, calculating, monitoring, and reflecting the importance of multidimensional metrics and indexes in defining and measuring complex phenomena (22, 124). Tackling the challenge of developing a mechanism to quantify resilience will require multi-, inter-, and transdisciplinary approaches, pulling expertise from numerous disciplines and knowledges, combining methods, and engaging key stakeholders in problem framing and resolution (128).

5. TURNING FOOD SYSTEM RESILIENCE CONCEPTS INTO PRACTICE: QUESTIONS AND ISSUES

Food system resilience is a complex concept that brings together various aspects from both resilience as well as food systems thinking. And food systems resilience thinking is still very much in flux, with definitions emerging through different disciplines and stakeholders using these in different settings. Although the COVID-19 pandemic brought the vulnerabilities of current food systems into the focus of the wider public, resilience thinking, what it constitutes, and how resilience of a food system can be enhanced (or built) still needs further exploration. A review of the projects in the Resilience of the UK Food System in a Global Context program (14) and associated literature have shown that moving these concepts into practice and operationalizing them in different food systems (sub)settings with their specific contexts, actors, geographies, history, and culture raises a variety of questions. In this section, we lay out these questions resulting from the concepts laid out in Section 4 and identify a set of issues that require further investigation.

5.1. To What Degree Is Food System Resilience an Emergent Property?

Allen et al. (129) note that the theory behind the definition of resilience as an emergent property is well-developed and not only embraces complexity and the role of diversity but also accounts for scale-specific dynamics that are critical in determining and understanding SES dynamics. For policy- and decision-makers, the important question is whether anything can be done to capitalize on this emergence so as to enhance the resilience of a food system and, if so, what? If food system resilience is indeed a property of the system, then one can argue that actions to change the shape (number and type of food system actors) or the structure (how they relate to each other) could help to build a more resilient system. What actions and policies lend themselves to resilience-building in a particular food system depend of course on its vulnerabilities to a particular shock or stress. Because of this, answering the four questions described in Section 4 can be seen as a key first step in any undertaking to build more resilient food systems and also calls for a participatory process that brings in the various food system actor perspectives. If resilience is an emergent property of a food system, can actors actively shaping the food system activities and food system structure influence the resilience of a whole food system, or can they influence only their own level of resilience toward a particular shock or stress?

5.2. Is an Overall Game Plan Needed to Enhance Food System Resilience?

As food systems are in urgent need of action to transform food system outcomes, how to coordinate a myriad of different actors and agree on the direction of change have become important questions for researchers and policymakers alike. The notion of developing a game plan or so-called systemic innovations (130) has been proposed to enable a more efficient way of changing a whole food system as opposed to parts of the system. With respect to food system resilience, this then begs the questions of whether and how this notion also applies to resilience-building. This is particularly important for the resilience notion of reorientation, as here resilience is coupled with reorienting activities to also achieve better, more resilient, and sustainable food system outcomes. Is coordination across actors, at least within a specific subsystem, needed to achieve resilience? And if so, how can this be achieved and assessed?

5.3. How Can Food System Resilience Be Assessed?

Most research considering resilience focuses on single variables and uses simple models, failing to consider the system as a whole and the complexity of relationships among multiple variables to create synergies or balance (131–133). Although multivariate approaches have been tested (126), these still fail to consider multiple components of resilience. Thus, if we want to assess the resilience levels of a food system, either qualitatively or quantitatively, what are the key metrics to use here? Can and should we assess levels of food system outcomes in order to determine the resilience levels of a food system, or do we need other measures? If yes, what are existing metrics we could use, or what new ones would need to develop?

5.4. To What Degree Does the Resilience of Individual Actors Matter for System Resilience?

One can argue that as long as the specific food system activity is maintained at a sufficient level and supply can be maintained in other ways (e.g., via trade), the food system can be described as resilient. Nevertheless, individual food system actor livelihood outcomes could be compromised in the short and the long run. How can resilience be enhanced at the food system level in ways that advance the shared, public interest, and what would be the implication of pursuit of those broader public goals for various food system actors? This demonstrates the importance of the perspective of the decision-maker assessing resilience levels and for deciding on a course of action to maintain the resilience of all food system outcomes. Is there a need for governance arrangements that enable resilience-building from a system's level perspective while also accounting for possible trade-offs for individual actors? And can individual food system actors be resilient without the resilience of the underlying system (physical infrastructure, institutional settings, etc.) within which they operate? How do resilience levels of these different systems interact and influence each other for overall food system resilience?

Furthermore, how can resilience-building measures take existing power imbalances between different food system actors into account? Even if both the public and private sectors are mobilized to collaborate on food system resilience-building, we are then challenged to ask whether or not resilience at the food system level depends on the imbalances along the supply chain, especially on the resilience of the most vulnerable actors in the system. Given a high level of concentration in the markets behind global food systems, as well as continuous further mergers and acquisitions, a considerable amount of research warns of the risks to food security from power imbalances (21, 45, 134–136). At the same time, perfect competition on food markets can lead to nonresilient system outcomes as well. Empirical cases show that cooperation between food system actors, financial capacity, and infrastructure can enable better shock mitigation, even though implying some power on the market. This begs for more precise analyses to assess functional diversity, supply chain redundancy, incentives and accountability (ownership) of powerful firms in the food system, as well as a thorough evaluation of efficiency versus resilience trade-offs (21). A combination of firms of different sizes might be conducive to building resilience at multiple levels (137). The question of what is the role of power and governance in resilience-building and how can it be used to increase resilience rather than create additional vulnerabilities continues to be important.

In relation to governance arrangements, it is critical to identify the responsibilities of each actor for enhancing their resilience capacities. For example, is it an individual, household, business, charity, or government responsibility to prepare for the risk of rising food prices? Who should attempt to prepare for catastrophic food system shocks?

6. CONCLUSION

Although the need for building resilient food systems was brought to the attention of the wider public by the disruptions of the COVID-19 pandemic, policymakers and academics have been worried about the various vulnerabilities inherent in our complex food systems for many years. Recent decades have seen different disciplines including ecology, psychology, and engineering developing resilience framings. Our review of how these have more recently been applied and further developed for food systems placed them in a context of actors and their activities, the drivers that influence the actors' activities, and hence the outcomes of these activities. We found that considering what resilience means in this food system context first requires setting clear boundaries by answering four framing questions: resilience of what, to what, from whose perspective, and over what time frame. It then requires clarifying which type of resilience strategies food system actors aim for: robustness, recovery, or reorientation (the 3 Rs). Each of these strategies entails actors adapting their activities.

Multiple questions, however, remain as to what these adaptations mean for overall food systems resilience, for other food system actors, and how to asses resilience levels. It is also unclear how individual actors' actions contribute to overall food system resilience, or if food systems resilience is an emergent property varying on the basis of the shape and structure of the system. A further consideration is how food system resilience and sustainability interact. These are different concepts and will require different actions to manage potential trade-offs between food system outcomes. This points to the need to assess the degree to which resilience and sustainability aims can be mutually compatible, as indicated by our reorientation strategy. Key issues to consider are who decides on what strategies to pursue, how to shape agenda setting, and the different levels of power food system actors have to shape the system. Food system actors and other stakeholders will also need to agree on a set of variables to monitor to determine if resilience is being enhanced.

Progress on all of these issues is urgently needed if we are to better mitigate further food system shocks and stresses, which are likely to hurt society's most vulnerable first. Such progress will require cooperation, coordination, and negotiation among the various food system actors so they adapt their activities to transform the health, environmental, social, and economic outcomes where suboptimal. This needs to be based on a better understanding of the dynamic complex interactions between food system drivers, actors, activities, and outcomes to help identify interventions that hold the best potential for enhancing food system resilience.

SUMMARY POINTS

1. Food systems are vulnerable to a range of interacting shocks and stresses. Shocks are abrupt events of differing probability of occurrence and severity of impact, and may even be wholly unimagined. Stresses are longer-term drivers or conditions that are more easily perceived and will influence change either directly or indirectly.
2. Food system outcomes of food security, other social and economic goals, and environmental conditions need to be made more resilient to shocks and stresses.
3. Building food system resilience needs to consider how to deal with complex and uncertain feedbacks and trade-offs across the different food system outcomes, and different perceptions of the desirability of those outcomes between different actors. This requires a pluralist approach and mechanisms to visualize and assess trade-offs across food system actors to achieve given food system outcomes across multiple scales.
4. Answers to a set of framing questions are needed to set a clear boundary for discussions: Resilience of what? Resilience to what? Resilience from whose perspective? Resilience for how long? Answers to each of these questions iteratively inform the others and depend on who is involved in answering them, and on whose behalf.
5. Most policy, practice, and societal discussions focus on enhancing resilience of the food system outcomes (i.e., food security, other socioeconomic goals, and environmental conditions). Emphasis is usually placed on either robustness (preventing the outcomes from changing) or recovery (returning to the original outcomes after a shock). A third concept, reorientation, involves food system actors and other stakeholders accepting alternative food system outcomes before or after disruption, but this will require negotiating trade-offs between outcomes and between different food system actors.
6. Irrespective of whether food system actors and other stakeholders agree on a robustness, recovery, or reorientation strategy, enhancing resilience of food system outcomes will require food system actors adapting their activities. Activities do not change spontaneously but in response to an opportunity or a threat. Adapting food system activities either marginally or substantially will transform the food system outcomes either marginally or substantially.
7. Encouraging actors to change their activities requires changing the policy, economic, social, and/or technological drivers that influence how different food system actors undertake their respective activities.

8. Operationalizing resilience-building involves normative choices but will result in decisions about trade-offs amongst food system outcomes. The relative value of different types of outcomes, for example, food price and accessibility versus environmental impact, is central to informing how trade-offs are to be managed. Trade-offs among different actors with different value sets and aims therefore need to be negotiated.

FUTURE ISSUES

1. Developing strategies to enhance food system resilience depends on an analysis of synergies, trade-offs, and unintended consequences. Successful trade-off optimization remains dependent on clear and consistent priority setting and the definition of "red lines" that cannot be crossed. A critical point that lacks theoretical development is by what (or whose) standards, and at what spatial and temporal levels, does society measure the outcomes of a resilient system and decide whether or not they are desirable and to whom?
2. To what degree is food system resilience an emergent property and what factors, and interactions between them, contribute to it?
3. To what degree does the resilience of a food system depend on individual actors in a given activity being resilient or on the activity itself being resilient?
4. By how much do given food system activities need to be adapted to transform given food system outcomes by set amounts?
5. Does an overall game plan based on systemic innovations need to be agreed upon by multiple food system actors to enhance food system resilience, or can a system's resilience be enhanced from relatively uncoordinated adaptation of individual actors' activities?
6. How can we best assess food system resilience and what kind of metrics, qualitative and/or quantitative, do we need?
7. How do approaches to enhance resilience of desirable food system aspects differ from those needed to overcome undesirable aspects of food system resilience?

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