Realizing Resilient Food Systems

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Food systems are under increasing pressure to produce sufficient food for the global population, decrease the environmental impacts of production, and buffer against complex global change. Food security also remains elusive for many populations worldwide. Greater emphasis on food system resilience could reduce these vulnerabilities. We outline integrated strategies that together could foster food system resilience across scales, including (a) integrating gender equity and social justice into food security research and initiatives, (b) increasing the use of ecological processes rather than external inputs for crop production, (c) fostering regionalized food distribution networks and waste reduction, and (d) linking human nutrition and agricultural production policies. Enhancing social–ecological links and fostering adaptive capacity are essential to cope with short-term volatility and longer-term global change pressures. Finally, we highlight regional case studies that have enhanced food system resilience for vulnerable populations. Efforts in these areas could have dramatic impacts on global food system resilience.

Keywords: agroecology, global change, food security, human nutrition, social–ecological systems

Extensive public and private investment in agricultural research and development has focused on increasing yields of key commodity crops in response to predicted increases in energy-dense diets as well as market dynamics and industry consolidation (Fuglie et al. 2012). Agriculture now produces more than enough calories to meet basic dietary needs worldwide (figure 1a); however, one out of eight people do not have access to sufficient food. Despite increases in global crop production, the number of undernourished people in the least developed countries has not declined (figure 1b); food-price volatility persists and is consistently higher in least-developed than in developed countries (figure 1c). Agriculture is also widely recognized as a key driver of global environmental change, which could ultimately undermine agricultural productivity (Steffen et al. 2015). Simultaneously, growing social and economic inequalities contribute to the coexisting challenges of malnutrition and overconsumption (Dixon et al. 2007). Systemic and transformative solutions are needed to address the intertwined global challenges of shifts toward resource-intensive diets, limited energy and water resources, decreasing crop diversity, diet-related health problems, and persistent undernutrition.

Applying resilience thinking to agriculture could help reduce food system vulnerabilities. We define social–ecological resilience as the capacity of food systems, including the actors within them (e.g., individuals, communities, farmers, and consumers), to cope with interacting and cumulative forces that undermine food access and equity (box 1). Sources of vulnerability operate at multiple time scales, including sudden shocks (e.g., catastrophic weather events), intermittent shocks (e.g., price volatility), and gradual pressures (e.g., climate change and shifting human diets). Individuals and communities can simultaneously experience multiple shocks or stressors operating at different scales.

Social–ecological resilience research has increasingly addressed *adaptive capacity*, or the ability of a system to self-organize and adapt in the face of disturbance (Carpenter et al. 2001). Social justice and inequalities can influence the ability of actors within a system to self-organize through distribution of rights and access to resources (Chappell and LaValle 2011). Therefore, although food systems can be resilient but inequitable, we argue that increasing equality via engaged participation by all actors increases adaptive capacity, supporting a transformation to a more resilient and equitable situation (Ensor et al. 2015). Here, we integrate these concepts to emphasize the attributes and strategies required for food systems to learn and adapt to stressors while simultaneously enhancing equity and social justice.

We present a critical analysis of key food system vulnerabilities, as well as strategies that could enhance resilience, improve individual and community well-being, and enhance environmental quality. These vulnerabilities and strategies represent "wedges" that influence food system resilience across production, distribution, and consumption components. Key strategies for transformation to more resilient food systems include the following: (a) addressing issues of gender equity and social justice that shape access to all food system components, (b) adopting integrated agroecological approaches to produce more food with reduced

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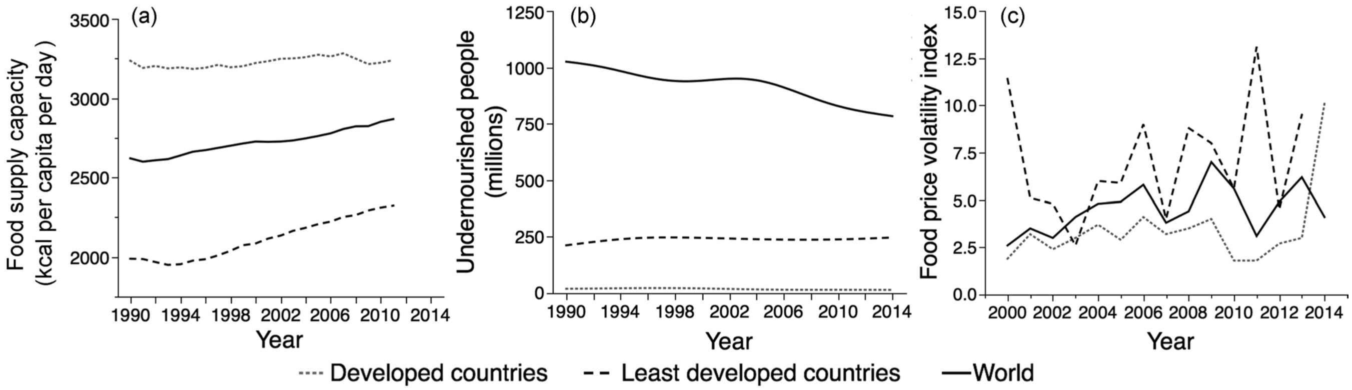

Figure 1. Recent trends in (a) per-capita food availability (1990–2011), (b) the number of undernourished people (1990–2014), and (c) the domestic food price volatility index (2000–2014) for the world, developed, and least developed countries (UN Classification). These trends emphasize how increasing food availability with more production or via imported production have not alleviated malnutrition in least developed countries. In addition, food price volatility remains a pressure on food security despite vast increases in food production. Abbreviation: kcal, kilocalories. Source: FAOSTAT Database.

Box 1. Food systems and resilience.

Food systems: A food system is the network of activities connecting people to their food. Food systems operate at multiple spatial scales and include production, distribution, and consumption components connected through complex social, ecological, and economic relationships (figure 2).

Accessibility: Accessibility is often defined as the physical and economic ability to acquire food. We expand this definition to include the concept of agency: the ability of people to influence sociopolitical systems, including access to wealth and resources.

Resilience: Resilience is the capacity of a system to withstand shocks and external pressures while maintaining its basic structure, processes, and functions. Resilient systems have buffering capacity, which enhances their ability to adapt to changes, learn from past mistakes, and recover from disturbances.

Food system resilience: We define resilient food systems as the capacity of people to produce and access nutritious and culturally acceptable food over time and space in the face of disturbance and change.

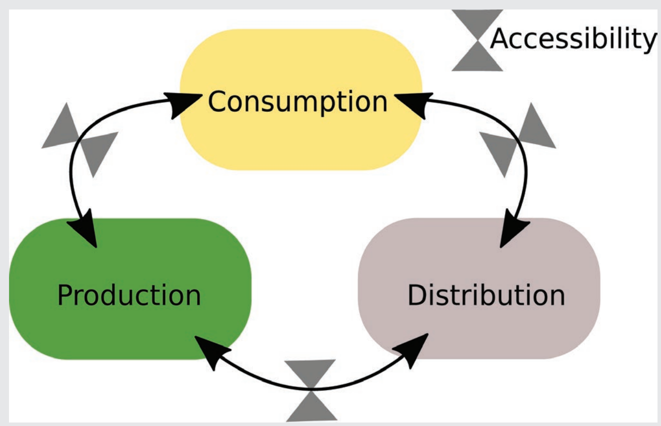

Figure 2. Links across food system components are often regulated by accessibility.

environmental impacts, (c) supporting more regionally organized food systems, and (d) embedding access to healthy and culturally relevant foods within production policies. We highlight case studies focused on smallholder farmers and poor urban consumers, which represent approaches that have integrated production, distribution, and consumption activities with measurable benefits for human health and well-being. We propose that such approaches—considered together as an integrated set of transformational wedges—could leverage local and regional food system resilience to promote or reinforce resilience at larger scales.

Vulnerability in accessibility: Gender and other inequities

Predicted increases in global food demand have become a justification for intensifying production practices often without addressing the systemic causes of food insecurity. Several interventions that are often more important drivers of food accessibility than total food production could ease global food demand, including increasing social justice and equity (Chappell and LaValle 2011), reducing food waste, and shifting diets (West et al. 2014). There is a large body of work demonstrating that improving gender equity and

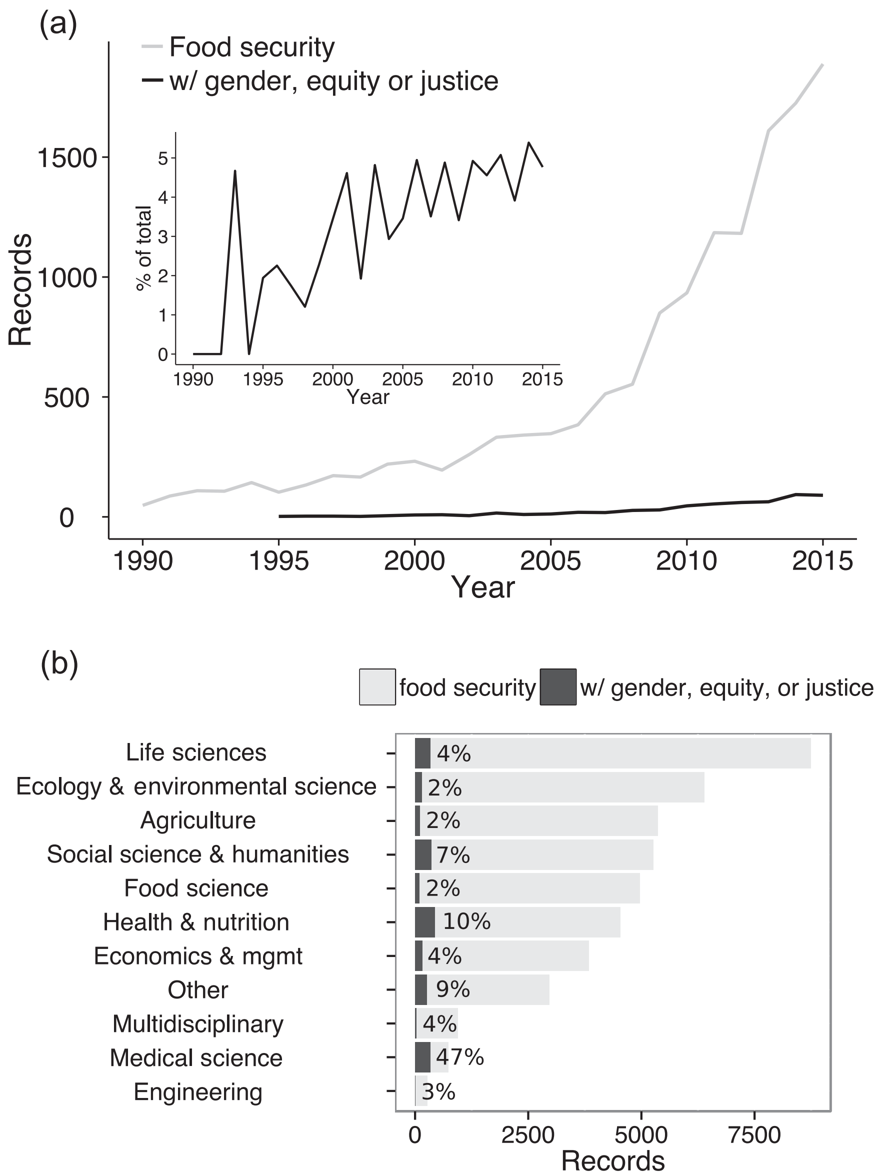

Figure 3. Publications between 1990–2015 on the topic of "food security" or "food system*" and those that also included topics of "gender or *equity or *justice" in the title, abstract, or keywords as (a) the number of records annually and the percentage of the total that included gender, equity, or justice (inset) and (b) the sum of all records by disciplinary category and the percentage within each category that included gender, equity, or justice. Source: Thomson Reuters Web of Science.

Despite strong evidence of the importance of equity and justice in addressing food system resilience, we find that less than 6% of food security publications over the past 25 years included the topics of gender, equity, or justice (figure 3a). Although the proportion of food security studies integrating gender, equity, or justice topics has increased slightly over time, integrated studies remain scarce in the agricultural literature and are more common in the social sciences, health, and nutrition literature (figure 3b). Medical sciences often included gender as a biological category rather than as a social factor, which contributed to the high proportion of medical science studies including gender, equity, and justice. A more diverse portfolio of research that addresses sociopolitical factors, especially gender inequities, is needed to identify actions that can enhance food system resilience.

Strategy for fostering accessibility: Equal access to capital and productive resources

An equity-based approach to improving food system resilience suggests the prioritization of communities that are most disadvantaged in terms of access to resources (Haddad et al. 2015). Policies and programs targeting disadvantaged populations, such as the urban poor and smallholder populations, can be more cost effective than nontargeted approaches in achieving measurable human well-being outcomes (Carrera et al. 2012). Because of women's large role globally in food production and household nutrition activities, strategies that address gender inequities are likely to increase both food security and food system resilience, including the ability of communities and households to adapt to change. Box 2 presents a case study from India as an example of how improving women's access to land and resources has improved multiple aspects of food access and human health. Boxes 3 and 4 provide further examples of food system strategies in Malawi and Brazil, respectively, that have successfully integrated issues of gender, equity, or justice with production and distribution strategies. The Malawi case study, in particular, illustrates how collaborative partnerships between agricultural scientists and communities can inform research questions and generate integrated solutions.

women's access to education has cascading benefits for family nutrition and child development. For example, recent analyses revealed that improving access to safe water and sanitation and increasing women's education and empowerment were equal or more important drivers of reducing child undernutrition than food supply quantity and quality across 116 countries over the past 40 years (Smith LC and Haddad 2015). In addition, inequity and injustice increase vulnerability to civil unrest, which is a key driver of famines and food shortages (Cederman et al. 2011).

Box 2. Collectives address gender inequities in India's agricultural sector.

Despite economic and agricultural productivity growth, India continues to experience severe malnutrition. About half of all workers in India are employed in agriculture, with 80% of farms less than two hectares in size. However, gender disparities undermine potential improvements in well-being from India's growing economy. Women occupy a large and growing role in agricultural production, but the productivity of women-run farms is hampered by unequal access to resources (e.g., land, credit, inputs, and technical support). These inequities arise from poverty and distributional inefficiencies but also reflect systemic gender discrimination within male-dominated agricultural extension services and land inheritance. An emerging approach to address gender inequity is the formation of all-women farming groups. These "bottom-up" collectives have numerous potential benefits, including greater leverage against exploitative contracts, skill and labor pooling, as well as shared capital investments (Agarwal 2010). Collectives are often initially supported by NGOs, such as the Deccan Development Society (DDS), which assists small women's groups in Andhra Pradesh to purchase or lease land, with a goal of enhancing food security through organic farming and diversifying cropping systems. Co-benefits observed in collectives across India included enhanced farm productivity, greater control over profits, improved family diets, positive health and education outcomes, and reduced caste or gender discrimination (Agarwal and Herring 2013).

Greater inclusivity of women translated to food system change beyond smallholder farms (Agarwal and Herring 2013). For example, DDS and women's groups have established community grain bins to buffer against production disruptions, improve distribution systems, and target accessibility for the poorest members (Agarwal 2010). Although initially a small-scale effort, the DDS illustrates how empowerment of vulnerable populations can promote well-being and more equitable food systems at larger scales, particularly when connected to existing larger-scale women's initiatives. Other organizations have begun replicating similar strategies throughout India, sometimes in conjunction with larger efforts in poverty reduction and food security, but the empowerment of women has been pivotal (Agarwal 2010).

Production system vulnerability: Intensification and homogenization

Diversification can mitigate vulnerability to variability (e.g., in climate, resource availability, or markets) and increase resilience in systems ranging from financial systems to natural ecosystems (Folke et al. 2004). However, global agricultural systems have experienced immense homogenization and specialization over the past 50 years (e.g., Khoury et al. 2014). As production systems intensify, the consolidation and concentration of sources of seed, technology, fertilizers, and pesticides increase the dominance of a small number of commodity grain crops with a narrowing genetic base (Pingali and Traxler 2002, Khoury et al. 2014).

This specialization and intensification has improved yields—but at large costs for environmental quality and resilience (Bennett et al. 2014). Over the past 50 years, global agricultural production increased by 47%, supported by 5.6-fold and 2.5-fold increases in nitrogen and phosphorus fertilizer inputs and contributing to over 400 marine hypoxic zones worldwide (Diaz and Rosenberg 2008, Foley et al. 2011). Simplified systems with low genetic and taxonomic diversity are also vulnerable to pest and disease outbreaks as evidenced by the rapid rise of herbicide resistant crops over the past 40 years due to singular reliance on herbicides in pest management (Mortensen et al. 2012). Simplified production systems can be more vulnerable to climate variability because of dependence on the success of one or two crops (Schlenker and Lobell 2010). Reliance on fossil fuel–based inputs and the geographic concentration of production centers could also compound farmer and consumer vulnerability to global food price volatility (Elser et al. 2014). For example, the global food crisis of 2007–2008 and US droughts in 2012 each contributed to grain price fluctuations (Headey 2011). This vulnerability is currently moderated in wealthy economies through governmental policies and market mechanisms, although many people in more wealthy countries still experience food insecurity. In the United States, this vulnerability has largely been targeted through crop insurance subsidies for a small number of commodity crops.

Production system strategy: Fostering resilience through agroecology

Increasing the use of ecological processes—in place of chemical-based inputs—has repeatedly been promoted as a strategy for sustainably feeding the growing global population (Godfray and Garnett 2014, Ponisio et al. 2015). Agroecological approaches seek to ensure long-term productivity through the restoration of biodiversity and the full array of ecosystem functions that support food production and human well-being (i.e., clean water, nutrient cycling, and climate regulation). For example, increased biodiversity in space and time has benefits for nutrient retention or recycling and builds soil organic matter reservoirs (Drinkwater and Snapp 2007, Kremen and Miles 2012), with benefits for resilience to drought and fertilizer dependency (Gardner and Drinkwater 2009). Crop diversity and enhanced landscape diversity through diverse field border plantings can increase multitrophic pest regulation, reducing reliance on external pesticide inputs (Lundgren and Fergen 2011).

Furthermore, the presence of certain plant functional groups can have disproportionate impacts on ecosystem

Box 3. Integrating agroecology and human health in Malawi.

Malawian agricultural investment has largely focused on modernization to stimulate production and rural development. Ranging from 8% to 16% of the national budget, the Farm Input Subsidy Programme aims to help farmers achieve food self-sufficiency and raise incomes by improving access to agricultural inputs, but there is continued debate about the program's costs and benefits (Jayne et al. 2015). Although maize-production gains have been attributed to the program since its establishment in 2005, hunger and child malnutrition remain major problems nationally, and poor farm households do not benefit as much as better-off households (Jayne et al. 2015). Also, the focus on inorganic chemical fertilizer only serves to mask the underlying issue of declining soil fertility, which jeopardizes long-term yield productivity.

Although national food policy in Malawi struggles to address major malnutrition problems, a participatory research effort in Ekwendeni, Mzimba District, has shown the potential benefits of integrating agroecological farming practices with broader social issues. The Soils, Food, and Healthy Community Project (SFHC) began as a pilot project in which farmers tested the efficacy of intercropped legumes as a chemical fertilizer alternative. Farmer research teams taught and mentored other farmers, and over several years grew to a network of 8,000 farmers using this method (Msachi et al. 2009). Legume crops helped improve soil fertility, increased maize yields in rotation, increased soil cover and also became an important dietary component for farm families (Snapp et al. 2010). However, farmers and academic researchers identified issues related to gender and other social inequities, child feeding practices, and HIV/AIDS that serve as barriers to broader improvements in family health and income. By integrating agricultural and social solutions, using community educational strategies, SFHC was able to address underlying issues that hindered the effectiveness of the agroecological system. For example, gender equality and good farming practices were promoted by encouraging men to share in traditionally female activities, such as legume residue management and food preparation. The result has been a network of thousands of farmers who have improved soil fertility, community cooperation, reduced dependence on external inputs, and reduced child malnutrition (Bezner Kerr et al. 2010). SFHC initiated a new Malawi Farmer to Farmer Agroecology project in partnership with university researchers to scale out to northern and central Malawi with 6000 households using these same approaches.

function. For instance, shifting from annual crops to perennial crops has the potential to substantially improve ecosystem functions. Compared with perennials, annuals rely on regular disturbance, are less competitive with weeds, and usually have a limited capacity to take up water and nutrients. Restoring perennials to agricultural landscapes, either in crop rotations or in field borders, could confer resilience and substantially improve numerous ecosystem functions (Smith TE et al. 2014). Ongoing efforts to perennialize major grain crops such as wheat offer even greater potential for building resilience and restoring ecosystem function. Legumes are another example of a plant functional group that enhances agroecosystem resilience while also having co-benefits for human nutrition and the environment (Snapp et al. 2010).

Agroecological approaches are well suited for improving food security and resilience in farming systems because of agroecology's transdisciplinary approach, which includes social science and food justice movements (Levidow et al. 2014). The case study focused on rural, smallholder producers in Malawi shows links among equity, human health, and nutrition in smallholder production systems (box 3). A nationwide fertilizer subsidy program, although increasing overall maize production, failed to address severe food insecurity and child malnutrition in Malawi (Chirwa and Dorward 2013). In contrast, agroecological methods for improving soil fertility and crop diversification simultaneously addressed ecosystem service provision, gender inequality, and child nutrition (box 3). As illustrated in the Malawi example, changing field management practices alone will not address broader socioecological challenges. The conversation about how to feed a growing population, therefore, needs to integrate agroecological production approaches with the simultaneous transformation of distribution, consumption, and accessibility food system components.

Distribution system vulnerability: The double-edged sword of globalization

Improvements in food self-sufficiency in many countries have been a dual result of increasing domestic production as well as increasing crop imports (Porkka et al. 2012). More than one-fifth of global calorie production is exported (MacDonald et al. 2015). However, there is considerable variation in the dependencies of countries on international food imports. Almost one billion people were fundamentally dependent on imports to meet their basic dietary needs because of resource constraints or shortfalls in production circa 2000 (Fader et al. 2013). The expansion of trade has therefore helped to increase food availability in many net-importing countries—but potentially at the cost of reduced resilience through reliance on foreign sources of food over which these countries have little to no agency and cannot always afford. The nature of food imports also varies, often dominated by imports of livestock feeds and, in some cases, increased supplies of less healthy, more processed foods. Furthermore, the degree to which trade has displaced or undercut the incomes and food security of local farmers or diverted from investment in increased indigenous productivity is largely unassessed.

Globalization poses complex tradeoffs for food system resilience across scales. Globalization increases distances between producers and consumers, both geographically and in terms of access to information (Clapp 2014). Growing interconnectedness in food systems means that social, economic, and ecological vulnerabilities are also connected across increasingly vast distances (Adger et al. 2008)—but often with limited transparency. Some countries outsource land use abroad either indirectly or through foreign direct investment via large-scale land acquisitions, or land grabs. Most new cropland expansion globally can be attributed to the production of crops for foreign exports (Kastner et al. 2014), especially commodity crops in tropical countries (DeFries et al. 2013). These dynamics have potentially large consequences for developing countries' autonomy *vis-à-vis* food systems and social equity, including impacts on rural livelihoods (Golay and Biglino 2013). The physical separation of production and consumption activities has also displaced environmental impacts of production to exporting countries. For example, global trade in livestock feed has contributed to vast phosphorus surpluses and degraded water quality in some regions, and the depletion of soil phosphorus in other regions, while also reducing the capacity for recycling this crucial nonrenewable resource (Schipanski and Bennett 2011).

Distribution system strategy: Fostering resilience through regionalization

Achieving resilience in the food system may require efforts to counter the concentration of the global production of an increasingly narrow set of crops in key export-oriented agricultural regions (Kastner et al. 2014) by sourcing food from multiple scales of distribution and diverse markets and supporting polycentric loci of decisionmaking. Similar to the benefits of diversity in cropping systems for risk management, diversifying distribution networks has the potential to improve the stability of food availability when disruptions occur. Increasing emphasis on local and regional food systems could foster more rapid innovation and the ability to adapt to global-change forces (Ostrom 2010). Regional and local food systems also create social embeddedness between producers and consumers, fostering greater attention to social inequities and agroecosystem management (Migliore et al. 2014).

We propose regionalization as an important intermediary between local and globalized production. We define regionalization as the clustering of local food production and distribution activities to leverage greater access to infrastructure, resources, and/or markets. Such a strategy could enhance the food self-sufficiency of a given region by closing yield gaps (West et al. 2014), promoting regenerative capacity (Benson and Garmestani 2013), reducing waste, and recycling nutrients. Regionalization offers an integrated approach to help support smallholder and agrobiodiverse farms and focuses on providing regionally adapted, diversified diets while theoretically increasing the capacity for more closed-loop resource use. Acknowledgment of the nested nature of food systems (local, regional, and global) in food and agriculture policy could enhance food system resilience while not limiting the potential benefits of international trade to meet demands globally, including access to foods not grown domestically.

Cities represent a unique challenge for building resilient food systems with diversified distributions systems. Urban centers are often highly dependent on globally traded foods (Ercsey-Ravasz et al. 2012). Despite positive correlations between urbanization and global individual income growth, urban centers tend to have similar or higher rates of poverty, income inequality, and food insecurity as rural areas (Satterthwaite et al. 2010). The urban poor are especially vulnerable to global food price volatility, as seen in the food crisis of 2007–2008. The drivers of food price volatility include but are not limited to energy prices, trade policies, regional food production shifts, civil unrest, and speculation (Headey 2011). To increase the buffering capacity of urban food systems, models are emerging that strengthen links between local and regional food systems in addition to maintaining links to global systems. Box 4 illustrates this food system resilience strategy focused on the urban poor and urban–rural links in Belo Horizonte, Brazil.

However, the capacity for a country or region to provide a nutritious, culturally appropriate diet on a national or regional scale is highly contextualized based on production capabilities and the sociopolitical relationships that influence distribution networks. The challenges and opportunities for fostering food system links across scales depend on local context and political will to develop tailored policies, such as those developed in Brazil (box 4). Achieving such strategies will work against some multinational corporate interests and will require political change and shifts to more adaptive governance systems. Similar to the limitations of relying solely on field-based agroecological practices, diversifying distribution networks is one part of a broader strategy to achieve more resilient food systems.

Consumption system vulnerability: Homogenization of energy-dense diets

Although globalization has played a role in regional food availability, it may also contribute to less healthy diets and overconsumption in some regions. The vertical integration of production, marketing, and distribution systems has contributed to an increasingly homogenous, calorie-rich, and land-intensive global diet (Cassidy et al. 2013, Khoury et al. 2014) and to the simultaneous prevalence of chronic diseases, including type-2 diabetes, obesity, and some cancers alongside hunger (Hawkes and Popkin 2015).

How we define and respond to projected food demands will shape long-term food system resilience. Food-demand *projections* have been converted into food-production *goals* used to justify policies that support the simplification and intensification of production and distribution systems with implications for food accessibility (Loos et al. 2014). However, demand itself is strongly influenced by policies and commercial interests. This means that current projections conflate "wants" influenced by policy

Box 4. A regionally nested urban food system in Brazil.

Belo Horizonte is a city of approximately 2.5 million people located in southeastern Brazil. The Secretariat for Nutrition and Food Security (SMASAN) established food security programs to maximize food availability and accessibility by increasing the city's reliance on regional food sourcing, which simultaneously served to support regional farmer livelihoods. Linking urban consumers with regional rural producers stabilized rural household incomes and slowed rural to urban migration while improving food availability within the city (Rocha and Lessa 2009). SMASAN's strategies to strengthen rural–urban links focus on delivering high quality food to the urban poor through farmers markets, subsidized food vendors, a school meal program, and a food bank. These programs include requirements for sourcing food from regional producers and subsidies to reduce prices. For example, the School Meal Program is sourced 30% from family farmers (FAO 2014), and mobile food outlets are mandated to sell in low-income areas on the weekends at approximately 20% to 50% below market price in exchange for the opportunity to sell food in more profitable locations during the week (Rocha and Lessa 2009). Many of these municipal programs influenced, and were subsequently nested within Brazil's national food security program called the Zero Hunger Strategy. These national policies and programs allow for locally tailored solutions and facilitate access to national and global food markets in addition to the focus on local and regional supplies.

SMASAN also supports urban agriculture programs to supplement local fruit and vegetable supplies. Although the total quantity of food produced in the city is relatively low, increased vegetable consumption and social networks have been strengthened, and support for urban agricultural programs has increased substantially (FAO 2014). Support for nutrition assistance (through the distribution of enriched flour) and nutrition education has also reduced malnutrition. Compared with a decade ago, 75% fewer children are hospitalized for malnutrition, and 25% fewer people live in poverty as a result of programs that use 2% of the city's annual budget (Rocha and Lessa 2009). Belo Horizonte's spatially integrated food security programs have therefore achieved substantial progress in alleviating hunger while bolstering urban and surrounding rural economies.

and commercial interests for resource-intensive diets with the "needs" of those without *effective demand* (e.g., those lacking consumer purchasing power and access sufficient to match the level of their basic food needs; Loos et al. 2014). From a resilience perspective, the current trajectory toward more resource-intensive diets that threaten ecological resources and human health illustrates the lack of feedback and adaptive capacity within the current food system.

Consumption system strategy: Linking agricultural production to human health goals

The growing pressure to increase production represents an important food system vulnerability that can push systems over planetary boundaries of resource use (i.e., land, water, fertilizer; Steffen et al. 2015). Addressing this vulnerability requires the integration of food production and consumption sectors. We propose that public health goals should explicitly inform agricultural policies. Rather than assuming current consumption trends are immutable, the development of agrifood policy that supports growing the food to supply healthy human diets would provide a regulating feedback between the production and public health sectors. This health-centered approach focuses on the type of food produced, by whom, and for whom, which allows production gains to translate to human health benefits.

In the United States, policies supporting human nutrition programs and policies supporting agricultural production are contained within a single policy, the US Farm Bill. However, there is little to no integration across these two areas with contradictory aspects in the Bill influenced by political and commercial interests at multiple scales. In contrast, shifts to a more adaptive governance systems that focus on public goods and integrate diverse stakeholder groups operating at multiple scales could inform national policies designed to support diversified production systems that provide for nutritious, culturally relevant diets and could potentially drive a major shift not only in human-health outcomes and the trajectory of consumptive demand but could also have cascading benefits for natural-resource use globally.

Sustaining viable, diversified local and regional food systems can improve human health. For example, a single-factor study on human health could conclude that increasing the diversity of food imports will adequately provide dietary diversity; however, if the potential benefits of diversified production systems and reduced dependency on volatile global markets were included, increasing diversity across all sectors could contribute to more favorable human and ecosystem health outcomes. Recent studies support the links among crop diversity, the nutritional adequacy of diets, and human health (Jones et al. 2014), suggesting that incentives for the production of only a handful of crops may negatively affect human health and increase chronic disease risk. All three case studies (boxes 2, 3, and 4) provide examples of strategies that link social and ecological dimensions of food systems across scales with positive human health outcomes. The Brazil example illustrates the potential for proactive public policy to improve consumer access to diverse, culturally relevant diets. The links among production diversity, dietary diversity, and human health are an important emerging area of research.

Charting a path toward more resilient food systems

Currently, dominant approaches to addressing vulnerabilities in production and distribution components of food

Table 1. A summary of the characteristics of current, brittle food system strategies and the impacts of alternative, more resilient strategies based on specific case studies from India, Malawi, and Brazil described in boxes 2, 3, and 4.

Country	Contemporary brittle system	More resilient system strategy
India	*Status quo*	*Intervention to increase women's access to resources*
	≈ low productivity of women-owned farms	↑ equity in access to resources
	≈ gender inequality of resource access	↓ gender discrimination
		↑ productivity of women-owned farms
		↑ capacity to invest in distribution infrastructure
		↓ vulnerability to price volatility
		↓ malnutrition
Malawi	*Subsidization of fertilizers*	*Agroecological intensification coupled with social strategies*
	↑ inequity in fertilizer subsidy distribution	↑ gender equity
	↑ synthetic fertilizer use	↑ diversity of crop rotations through legume adoption
	↑ maize yields	↑ soil fertility
	≈ soil fertility	↑ dietary diversity
	≈ malnutrition	↓ malnutrition
Brazil	*Status quo of urbanization*	*SMASAN food security programs*
	≈ rural and urban poverty	Government investment (2% of city budget)
	≈ dependence on food imports	↑ regional food supply
	≈ vulnerability to global price volatility	↑ stability of rural farmer livelihoods
		↓ urban migration
		↑ urban poor food access
		↑ dietary diversity
		↓ malnutrition

The arrows indicate the observed directionality of the effect, and '≈' represents no change.

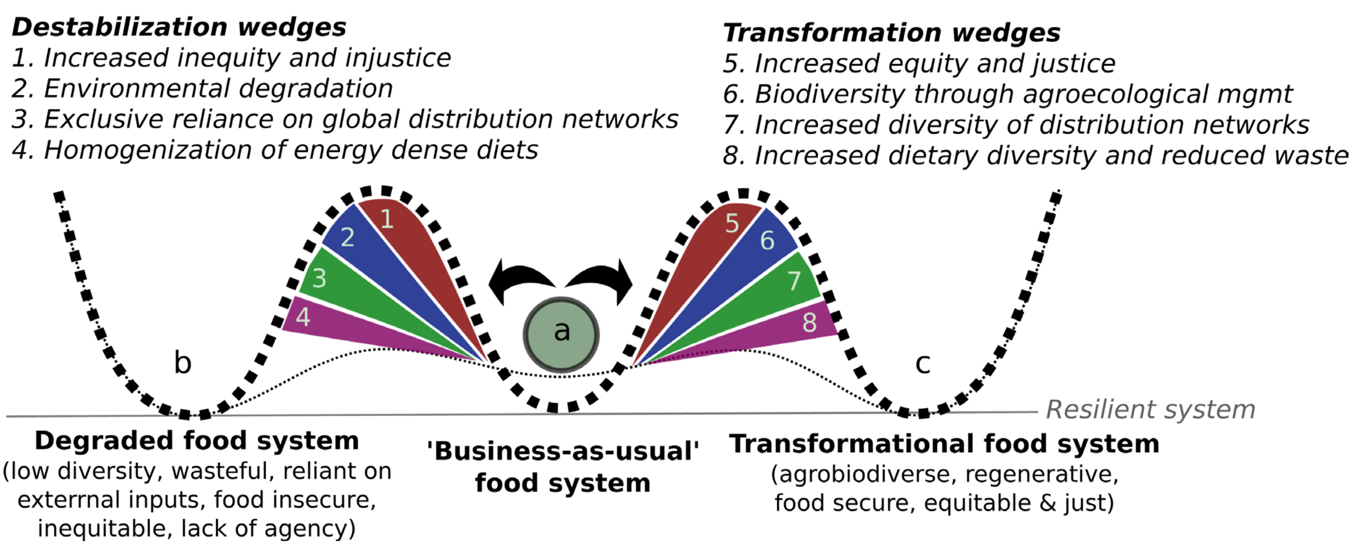

Figure 4. Conceptual model showing pathways that could shift current food systems (a) toward either a more degraded state (b) or toward a more social–ecologically sustainable state (c). The resistance of the current system to change can be shifted by destabilization or transformation "wedges." Each wedge can exert a specific force on the "business-as-usual" food system—whether positive and promoting transformational change or negative and leading to a more destabilized or degraded state. However, some of the wedges may interact with one another and they should be viewed as integrated.

systems emphasize regulation, including policies and price support systems, such as crop insurance, trade liberalization, and incentive programs. Although some regulatory elements offer an important safety net, others may reduce the ability of food systems to adapt to disruptions at either short or long timescales (Bennett et al. 2014). In addition, they do not address underlying drivers of these vulnerabilities—such as inequity, environmental degradation, the concentration of global distribution networks, and the homogenization of energy-dense diets—that could further destabilize and degrade food systems (figure 4). Resilient systems incorporate internal feedback mechanisms, maintain redundancy, and promote responsive governance and diversification at almost all levels (Cabell and Oelofse 2012). Here, we developed a vision for resilient food systems that includes the production of a diversity of culturally appropriate food items using agroecological principles that reduce reliance on external inputs rather than the overproduction of crops primarily for livestock feed, using energy and resource-intensive practices.

Addressing gender inequities and social injustice while fostering community-level self-governance could enhance the adaptive capacity in food systems by prioritizing local solutions as outlined in our case studies. The case studies and strategies described here illustrate how improving food and resource accessibility for the most vulnerable populations could have far-reaching impacts for food security, human well-being, and the environment. Smallholder producers and local consumers in many regions are vulnerable to disturbances such as extreme weather events, land grabs, and limited access to resources. The examples from Malawi, Brazil, and India represent innovative strategies that have all had measurable impacts on improving human health through the integration of production, distribution, and consumption activities with improvements in social equity (table 1).

The relative impact and scalability of the successful local and regional strategies we present is challenging to assess. Over the past 25 years, India, Malawi, and Brazil have all seen improvements in their global hunger index (GHI), a measure integrating undernourishment and child wasting, stunting, and mortality (IFPRI 2015). Brazil has made a large national investment (approximately 2% of national budget; FAO 2014) in reducing hunger through policies targeting food systems at multiple scales, including support for programs such as SMASAN in Belo Horizonte. Brazil's GHI score declined by 73% over the past 25 years. In contrast, the GHI of Malawi declined by 54% over this same period while investing approximately 10% of the national budget in fertilizer subsidy programs, and India's GHI declined by 40% (IFPRI 2015).

Ultimately, these case studies illustrate how integrating multiple strategies, or "wedges," can have a cumulative effect on food system resilience that is dependent on local or regional context. However, missing any one of these wedges at any given scale could undermine resilience and have a ricochet effect across scales (figure 4). Transformation wedges include investments in integrated solutions adapted to the local and regional social–ecological contexts of production, distribution, and consumption—coupled with local efforts to increase access to resources by addressing systemic inequities—that could have cross-scale outcomes that vastly improve equitable and sustainable food system resilience globally. In contrast, destabilization wedges—such as environmental degradation, the concentration of production and distribution systems, and inequities—have the potential to undermine food system resilience. Linking food system research with social movements focused on reducing poverty and injustice could help build partnerships needed to target successful strategies, fostering more just, sustainable, and resilient food systems.

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