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DISCUSSION PIECE

Identifying attributes of food system sustainability: emerging themes and consensus

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Abstract Achieving food system sustainability is one of the more pressing challenges of this century. Over the last decades, experts from diverse disciplines and intellectual traditions have worked to document the critical threats to food system sustainability and to define an appropriate agenda for action. Nevertheless, these efforts have tended to focus selectively on only a few components of the food system or have tended to be framed in particular discourses. Depending on the point of departure, what aspects of the food system are considered threatened, and what must be sustained, can differ greatly between perspectives. In this article, we draw from systems-thinking and social-ecological systems concepts to focus on the underlying process-related attributes that could support a more sustainable food system. We then examine the support for specific system attributes in six different knowledge domains addressing sustainable agriculture and food. From this review, we identify five system attributes—diversity, modularity, transparency, innovation and congruence—that are repeatedly featured in the different knowledge domains as critical aspects of food system sustainability. We argue that in the face of considerable complexity and high uncertainty, these attributes can serve as a guide to conceptualizing food system choices adaptively and iteratively.

Keywords Food systems · Sustainability · Food security · Socio-ecological systems

Abbreviation
FSS Food system sustainability

Introduction

Over the last decades, experts from diverse disciplines and intellectual traditions have worked to document the critical threats to food system sustainability (FSS) and to define an appropriate agenda for action. Nevertheless, these efforts have tended to focus selectively on only a few components of the food system (e.g., production, consumption, or distribution), or have tended to be framed in particular disciplinary discourses (Foran et al. 2014). Depending on the point of departure, what aspects of the food system are considered threatened, and what must be sustained, can differ greatly among distinct communities of experts and practitioners. Furthermore, because food system problems manifest at different spatial scales, solutions and the theory and evidence used to guide those solutions also tend to be scale-specific. As a result, interventions designed to enhance sustainability may work at one level but fail to improve or even decrease sustainability at other levels or scales (Thompson 2007).

In the face of high uncertainty about social and environmental change, decision-makers in diverse contexts are challenged to define a specific intervention or even a

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particular vision of the future as "sustainable," and seek guidance in these pursuits. While there is increasing agreement on what the desired outcomes should be for food system sustainability, there is less consensus on the appropriate means to achieve it. Agreement on a pathway forward is undermined by different terminology, distinct entry points into understanding food system dynamics and functions, and lack of clarity on how to best organize food systems to meet the diverse goals and outcomes desired.

While reference to the food system is increasingly common in public policy and research, in practice, what is understood as a food system incorporates everything from configurations of supply chains and distribution networks, to understandings of material flows, to the application of social-ecological system frameworks and approaches (Sobal et al. 1998; Ericksen 2008). In this paper, we argue that greater use could be made of social-ecological concepts that bring explicit attention to system dynamics and provide structure to guide sustainability pursuits. To date, this approach has not been extensively used to address questions of food system sustainability, despite the potential utility for food systems scholarship. Drawing from social-ecological literature and theory, our objective is thus to identify and interrogate a concise set of attributes that (1) influence significant functions of food systems that need to be sustained and (2) have greatest resonance across different approaches to food system sustainability. Our proposition is that an explicit use of social-ecological systems concepts in FSS research and practice may advance a common lexicon and bring a constructive focus upon which wider agreement may emerge on how specific system attributes can support the diverse outcomes desired in FSS.

Our approach is as follows. We begin with a working definition of a food system and what this concept brings to an analysis of sustainability. We then briefly review common understandings of sustainability and associated generic principles. We then explore the emergence of social-ecological systems in sustainability research and discuss system attributes associated with resilience and sustainability that have been derived from this work. We then examine the nature of support for these attributes in distinct knowledge domains associated with FSS. We conclude with a discussion of potential tradeoffs if such attributes were adopted as guidelines for FSS interventions across scales.

What is a food system?

The concept of a food system has risen in prominence in recent years as a growing body of research, policy, and activism has sought to address the complex intersecting processes associated with food (Ericksen 2008). Systems-based approaches provide a framework to understand the interactions among multiple challenges, such as food insecurity, environmental degradation, and chronic poverty (Godfray et al. 2010). Whether arguing that a food system is what "transforms nutrients into health outcomes" (Sobal et al. 1998, p. 853), or that it is a complex network of actors, activities (from production to waste disposal), resource flows and outcomes (e.g., Heller and Keoleian 2003), most contemporary work on food systems acknowledges that food systems are both complex and heterogeneous, and integrate social, environmental and technological processes and attributes that span local to global scales (Ericksen 2008; Godfray et al. 2010).

Ericksen conceives of a food system as a *coupled social-ecological system*, in which efforts to achieve food security both influence and are influenced by environmental outcomes and broader aspects of social welfare and livelihood security (Ericksen 2008). Her framework for food system analysis incorporates not only the activities of a food system, but also the interaction of global biogeophysical and social drivers of those activities. Reflecting sustainability principles, Ericksen also highlights three domains of normative food system outcomes: food security, which she argues should be the central objective of a food system, environmental security, and social welfare. In this conceptualization, a global integrated food system is the partial aggregation of a plethora of smaller food systems interacting at finer scales of analysis.

We adopt Ericksen's framework and argue that sustainable food systems would ideally balance these outcomes, with ensuring food security as central to any effort in FSS (see also Hodbod and Eakin 2015). Today the most common definition of food security is that of the Food and Agricultural Organization (FAO 2013): "Food security exists when all people, at all times, have physical, social and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life." The FAO characterizes food security as having four dimensions: availability, access, utilization and stability. In the 2013 *State of Food Insecurity in the World*, the FAO proposed a complex series of determinants and outcomes as food security indicators, incorporating aspects of food quality, physical and economic access, capacity to utilize food effectively, and vulnerability to shocks. The food system activities include production, processing, distribution, consumption and waste, which, working together, are expected to produce food security.

Nevertheless, while there is wide agreement on these dimensions of food security, how to achieve these diverse dimensions of food security, *sustainably,* is contested. Our goal here is not to identify concrete strategies that would be widely acceptable. Instead, we aim to link concepts of system structure and function to specific ideas of sustainability in the associated literature on food and agriculture sustainability. In doing so, we hope to provide a common lexicon concerning desirable food system attributes that may, in some cases, serve to enhance the dialog among disparate domains of action to support shared sustainability goals.

Generic principles of sustainability

There is agreement globally that sustainability, in its most general sense, incorporates the pursuit of social equity and justice, human welfare (in the case of food systems, specifically food security), and environmental integrity (Leach et al. 2010). To make similar broad statements about sustainability concrete and actionable, scholars have sought to outline the principles that define sustainability in a way that will guide action and create measurable criteria for assessment. For example, Gibson (2006) sets out eight core generic criteria for sustainability assessments, which together emphasize inter- and intra-generational equity, governance, livelihoods and socio-ecological system integrity. Nevertheless, we have yet to identify a widely accepted set of assessment principles that can be used to guide action specifically in the realm of FSS.

In reference to sustainable agriculture, Thompson (2007) argues that the challenge of finding common ground in part has to do with the predominance of "non-substantive" definitions of sustainability, or definitions that are rooted in subjective interpretations of "what is good" and desirable. Non-substantive sustainability definitions may well articulate values and goals in relation to food system sustainability in one particular place, or regarding one population, while undermining or contradicting goals and priorities at other places or scales. Thompson contrasts such definitions with "resource sufficiency" definitions that focus on maintaining the desired outcome as long as possible into the future and "functional integrity" definitions, which focus on the maintenance of fundamental system functions in a dynamic and evolving world.

In our analysis we also recognize the importance of "non-substantive" definitions of sustainability that reflect the aspirations, values and beliefs of specific populations in particular places. Sustainability is inevitably a contested and political process in which societies may modify goals as they test interventions and experience and learn from their efforts. However, given that we are addressing the sustainability of food *systems,* defining food system sustainability and associated criteria in terms of maintaining critical system functions is clearly attractive. To cope with the complexity and unpredictability of food system dynamics, the pursuit of normative dimensions of sustainability must be based on a robust understanding of system interactions and underlying functions (Redman 2014).

Thus, for the purposes of our analysis here, we define a sustainable food system as one that achieves and maintains food security under uncertain and dynamic social-ecological conditions, through respecting and supporting the context-specific cultural values and decision-processes that give food social meaning, and the integrity of the social-ecological processes necessary for food provisioning today and for future generations. In pursuit of a "functional integrity" perspective on sustainability, we look to theory from social-ecological systems, which has been heavily influenced by theory and related research on complex adaptive systems (Berkes and Folke 1998). Because systems theory has sought to eschew disciplinary bounds and to employ an integrative approach, it is a useful entry point to examine the various treatments of FSS from various disciplines (Boulding 1956; Miller 1978).

Systems theory has inspired solutions to the human management of social-ecological interactions by focusing on system structure and balance, and the role of system attributes such as diversity, redundancy, and modularity (Levin et al. 2013). Often system theory is applied to natural resource management challenges to gain insights into how to maintain the integrity of a specific system in the face of disturbance, surprise or stress; in other words, to support system resilience. Scholars of resilience argue systems should be managed in ways that acknowledge the central roles played by diversity and redundancy, connectivity, modularity and feedbacks, and innovation and learning (e.g., Biggs et al. 2012; Walker and Salt 2006). Furthermore, the management system itself needs to be receptive to change through, for example, distributed (polycentric) governance and mechanisms of participation. Others have translated these attributes into explicit metrics for resilience assessment in the context of rural policy development (Schouten et al. 2012) and environmental management (Nemec et al. 2014).

Managing for system resilience is not the same as managing for food security, social equity or environmental integrity. Nevertheless, the identification of system attributes specifically designed to support FSS might "load the dice" in such a way that food system development pathways would be more likely to lead to more sustainable outcomes than not (see, for example, Wise et al. 2014 for a discussion of a similar approach to adaptation pathways). In the remainder of the paper, we consider the relevance of the system attributes that have been identified in the social-ecological literature as fundamental to maintaining system functions to FSS. Our approach is thus both deductive, in that we are cognizant of the support for such attributes as modularity, diversity, redundancy, and polycentricism in the social-ecological literature, and inductive, by using the existing literature of FSS to identify the system attributes that are implicitly or explicitly invoked in support of food and/or agricultural sustainability. The result, we hope, both resonates with system science and social-ecological system theory while reflecting the specific values and concerns expressed in the discourse of FSS.

Current food system sustainability discourse

FSS has been addressed from a variety of perspectives and disciplines; the diversity of knowledge contributing to food and agricultural understanding is vast. Nevertheless, there is relatively little literature that addresses FSS from a truly comprehensive perspective, encompassing the diversity of food system activities, drivers and outcomes. For example, there is a large body of literature on agricultural sustainability, yet that provides little insight into sustainability from a consumer perspective, where "food" rather than agriculture is the core concern. We thus initially approached the topic of FSS using the structural organization of the supply chain, exploring how sustainability is discussed in relation to each of the core food system activities from production to waste management. This approach, however, was unsatisfactory, leading to a singular emphasis on lifecycle analysis rather than deeper insights into the disparate approaches to FSS. Nevertheless, a closer examination of the associated literatures revealed how different points of entry into the food system—e.g., farm-level analyses versus conceptual work focused on individual consumers—tended to be tied to quite different disciplinary approaches, epistemological assumptions and theoretical concepts, despite the ostensible focus on FSS (Table 1). It is these differences that we find constructive for our purpose here.

From this initial review, we defined six overlapping domains of knowledge to represent a breadth of approaches on the sustainability of the world's food system. Each of these domains of knowledge and discourse tends to focus on specific elements of the food system for sustainability efforts. We define these domains in terms of this focus: Individual food security; Community food sovereignty; Human economic welfare; Agro-ecosystem integrity; Land change; and Global food democracy. While these domains do not necessarily cover all the pertinent perspectives on FSS, they provide a sufficient breadth and diversity to test the salience of system concepts and attributes.

By tracing these different solution-foci back to their grounding in food and agricultural system understanding and associated disciplinary biases, we can derive complementary (and sometimes contradictory) insights into the social, economic and environmental dimensions of FSS and the broader applicability of system attributes to diverse contributions to FSS analysis. While FSS literature is complex and nuanced, our purpose is to paint in broad strokes the core ideas of major domains of thought as a first step in exploring the validity of systems principles to food system analysis, rather than conduct a systematic review of the literature. For each of these knowledge domains, we ask two overarching questions: (1) What is the primary sustainability problem of focus and how is the problem explained? and (2) What, ultimately, is being sustained, and what interventions are advocated?

Individual food security

Primary problem emphasis and explanations

The focus on individual food security and human health outcomes as "what needs to be sustained" is strongly supported by over a century of work in public health, nutrition and associated sciences (Hammond and Dubé 2012). Food systems are approached as systems that exist with the purpose to nourish people in such a way as to sufficiently meet nutrient requirements (Sobal et al. 1998). Thus, sustainable food systems are those that provide consistent access to healthful, culturally appropriate foods sufficient to support optimal health outcomes (Hammond and Dubé 2012; Nordin et al. 2013). Much of the science of nutrition for example, has focused primarily on optimization of health through amelioration of malnutrition, and, more recently, the causes and consequences of over-nutrition (Schneeman 2003). Metrics of sustainability thus implicitly or explicitly focus on obtaining optimal health outcomes (e.g., reduction in morbidity or mortality, decreasing over/undernutrition).

What is sustained and how?

To contend with disparities in food access, poor food choices, and associated poor health outcomes, professionals and associated policy focusing on individual food security have traditionally focused interventions on bettering consumer knowledge, attitudes, and behaviors related to food, as well as working to improve healthy food access and household food security through nutrition and food policy (Keenan et al. 2001). While some interventions operate at the community-level, the ultimate aim is enhancing individual and household access to appropriate nutrition. For example, some work in community nutrition has focused on food environment mapping, including density and proximity of a variety of food venues in food deserts, as well as the quality and healthfulness of the foods these venues carry (Zenk et al. 2009; Ohri-Vachaspati et al. 2012). Efforts are also underway to make fruits and

Table 1 Knowledge domains in food and agriculture sustainability

Knowledge domain	How is problem defined?	What explains the problem?	What is the scale/unit of analysis?	What is being sustained?	What are solutions?	What are the metrics?
Individual food security	Malnutrition; under/over nutrition; rise of diet-related chronic disease	Nexus of: unhealthy food environments, inequitable access, poor dietary choices and behavior	Vulnerable populations and individuals	Human health outcomes and healthy food environments	Behavioral change; equitable food distribution; consumption incentives/disincentives	Reduction in morbidity/chronic disease; reduction in under/malnutrition; increased consumption of healthy foods
Community food security	Disempowerment and social injustice: lack of control over food resources, decisions, knowledge	Historical legacy of social marginalization and racism, particularly in urban areas	(Urban) communities and neighborhoods	Community empowerment and social welfare	Participation in food decisions and food environment, localization of food distribution and access	Growth in direct marketing; reduction in food deserts; increase in Food Policy Councils
Human economic welfare	Poor economic growth and poverty; lack of meeting basic needs	Inefficient resource use and markets, insufficient investment, poor governance	Poor populations in developing countries	Economic growth and population-level human welfare	Improved market infrastructure; livelihood diversification; appropriate technology; trade reform; extension	Reduction in chronic food insecurity and hunger-related crises; reduction in levels of chronic poverty
Agroecological integrity	Resource degradation by conventional agricultural practices; loss of traditional practices and knowledge	Dependence on external and synthetic inputs; inappropriate practices of industrial agriculture	Plot and farm-level	Agroecosystems, local knowledge, Agrobiodiversity	Land-sharing; Maximization of ecological synergies in production; minimizing external inputs; enhancing local knowledge	Stability of production; biological productivity of agro-ecosystems
Land change	Competition between mutually exclusive land uses with significant tradeoffs between human and ecosystem needs	Planetary resource scarcity, global population growth and ecologically destructive agricultural practices	Global and regional landscapes	Natural capital (focusing on biodiversity and forest cover)	Agricultural intensification and land-sparing; closing the yield gap; improving resource efficiency	Resource efficiency of agricultural output; Rate of land use change associated with agriculture
Global food democracy	Global commodification of food	Corporate control and primacy of capitalist principles in food production, processing, distribution and consumption	Global, national	Multiple values and meanings associated with food; food sovereignty	Alternative trade and food exchange networks; multi-functionality; social mobilization and activism internationally	Growth in alternative trade networks; inclusion of multi-functionality in global governance

vegetables better available both through corner markets and grocery stores, and through local food venues, such as farmers' markets and community supported agriculture programs (Holben 2010). Many efforts in this arena include interventions based on the theoretical foundation of health behavior change theories (e.g., Wharton et al. 2015), which assess the extent to which an individual can or does make behavior changes based on the tools, knowledge, and support necessary for behavior change success (Spahn et al. 2010). Other approaches include policy applications providing individual and household food assistance as a means of combating poverty-related dietary inadequacies (such as the Supplemental Nutrition Assistance Program, or SNAP, in the U.S.).

Community food security

Primary problem emphasis and explanations

The concept of community food security focuses principally on the problem of ensuring adequate and appropriate food access for urban communities (rather than individuals)—either as an endpoint in and of itself, or as a means of community empowerment, which is perceived as an essential step in community development (Block et al. 2011). Community food security recognizes the historical processes that have "shaped regions and social relations with vast differences in wealth, power and privilege" (Allen 2010, p. 295), and it characterizes itself as a reaction to the "destructive, disempowering, and alienating effects of large-scale political economic forces" (Allen 2010, p. 296). While a global, systemic understanding of food is acknowledged, analysis and action are typically promoted at the community or neighborhood-scale. A consequence of this decentralized and localized approach is that the literature on community food security is quite diverse, incorporating among other disciplines, urban planning, sociology, social justice studies, geography and public health (e.g., Pothukuchi and Kaufman 1999; Allen 2010; DeLind 2011; Dowler 2003; Block et al. 2011; Feenstra 2002; Connelly et al. 2011).

What is sustained and how?

Community food security targets the participation and empowerment of diverse individuals and communities to control their own food choices, diets and nutrition (Allen 2010; Winne 2009). Key themes are self-reliance, local economic development, democratic process and transparency, and access to fair, affordable and healthy food choices (Community Food Security Coalition 2012). While ecological aims are considered—particularly in relation to connecting urban populations to healthy, locally produced food—the overarching focus in much of the literature as well as practice is distributive and procedural justice: justice in access to resources and justice in participating in decisions about the food system. The solutions offered are social and political, rather than technological fixes (Allen 1999). The re-configuration of the food system at the community scale is seen as instrumental in bringing about local innovation and, potentially, global food system change, via, for example, greater community participation, localization of food sourcing, fostering ethical consumption, and through creating and supporting alternative trade organizations (DeLind 2011). Examples of such efforts include community gardens, locally or regionally focused food hubs, producer cooperatives and social-economy ventures that at once address healthy food availability in a more localized context while attempting to impact community economic and social development.

Human economic security

Primary problem emphasis and explanations

A third trajectory of food system sustainability work, associated with international development agencies and many national government agencies in the developing world, has focused on national and regional-level food supply, and the interdependence of poverty, hunger, and environmental degradation in sustainable rural development (World Bank 2008; FAO 2013). While this knowledge domain encompasses a wide range of philosophies, approaches, ideology and practices, all tend to have improvements in human welfare and economic viability as their central focus of concern. Food security and a productive food and agricultural industry are both inputs into a broader process of sustainable development (World Bank 2008), as well as specific economic and human development goals (e.g., Millennium Development Goals).

At the household level, FSS in the development context is typically an explicit feature in discussion of sustainable rural livelihoods, or the ways in which individuals and households organize their labor, resources and capacities to make a living and to make that living meaningful (Scoones 1998; Bebbington 1999). Such perspectives emphasize the role of institutions and policy in mediating the capacity of households to achieve their welfare goals, and highlight the importance of social networks, income diversity and access to economic opportunity as core attributes of the ability of a household to withstand shocks, obtain basic needs and move out of poverty (Ellis 2000; Scoones 1998).

At broader scales, FSS in the development context is an issue of national capacity for food provisioning and distribution, be it through the production of basic staples, adequate domestic transport and distribution infrastructure, or efficient trade networks (see for example, World Bank 2008). In the face of climate change, FSS has also been broached in terms of national security and resilience: supporting a country's capacity to cope with and recover effectively from exogenous shocks, through, for example, "climate smart agriculture" (e.g., Beddington et al. 2012; World Bank 2011).

What is sustained and how?

Consistent with these economic framings, sustainability of food and agriculture in this human welfare and economic security discourse prioritizes making agriculture and related food production activities more reliable, productive and profitable for those involved (Pingali and Pandey 2000; Pingali 2012; USAID 2011; World Bank 2008). Sustainability enters into the conversation primarily in terms of enhancing resource use efficiency through appropriate and innovative technologies, and broadening the participation of smallholders and women in remunerative agricultural activities (Pingali 2012). At the household level, agricultural activities are thus conceived as a means of poverty alleviation; at the national-level, enhancing trade, economic growth and private investment are predominant concerns. While environmental goals are clearly an increasing development concern, meeting basic human needs is unmistakably the foremost concern of development policy.

Agroecological integrity

Primary problem emphasis and explanations

One of the longer and more substantive conversations on food, agriculture and sustainability comes from the agronomic sciences and agroecological experts. Here the focus is on the use and management of human and natural resources essential for sustaining agricultural production, and the compatibility of agriculture with other ecological processes and services (e.g., Gliessman 1991; Altieri 1995; Dahlberg 1994; Scherr and McNeely 2008; Pretty 2008). While it is by no means the only approach to the study of alternative agricultural practices, agroecology—a science that provides ecological principles for the design and management of sustainable and resource-conserving systems (Altieri 1995)—has been central to the critique of industrial agriculture, and, in various ways, central to ideas about what reforms are needed to make agricultural practice more sustainable (Wezel et al. 2009). Agroecology focuses on maintaining farming in a resilient state through maximizing the processes and structures that mimic the dynamics of natural ecosystems and thus reducing agriculture's dependence on external inputs (Gliessman 1991; Altieri 1995). Many of these ecological processes are supported through increased biodiversity by ensuring that various ecological niches in an agroecosystem are occupied, and providing for the possibility of redundancy in ecological roles as insurance against potential hazards (Scherr and McNeely 2008). In addition to species diversity, genetic diversity is also an issue of concern, as it supports resilience and adaptability of the system, and preserves genetic variation for future research and hybridization (Harvey et al. 2008). More recently, agroecological research has moved from parcel- and household-level analyses to the landscape scale (e.g., Scherr and McNeely 2008; Perfecto and Vandermeer 2010), and into more political concerns of food sovereignty, the role of local knowledge in innovation, agricultural technology control, and biodiversity conservation (Wezel et al. 2009).

What is sustained and how?

From the perspective of agroecology and other approaches to eco-agriculture, the management of the farm plot and household is fundamental to sustainability at broader scales; failures in approaches to farm management ultimately explain the ecological, social and economic dysfunctionality of the contemporary global food system. Agroecology recognizes that agroecosystems are not self-sustaining, but rather are actively maintained through locally-derived human interventions, experimentation, learning and grassroots innovation to enhance the benefits from natural processes, such as pollination and nutrient cycling (Chappell and LaValle 2011). Some researchers have advocated that agroecology can support and empower smallholder farmers by reducing dependence on expensive inputs, diversifying their diets, relying on local knowledge and increasing the stability of production through maximizing synergies with ecological processes (Thrupp 2000; Altieri et al. 1998). In this manner, agroecology promises to support positive outcomes for productivity, rural livelihoods, and the environment and has been embraced by many proponents of grassroots sustainable development and smallholder food production.

Land change

Primary problem emphasis and explanations

The primary concern in this perspective is that efforts to meet future food needs will directly threaten the viability of ecosystems necessary to sustain biodiversity and essential planetary ecological services (Tilman et al. 2011). Thus the environmental externalities of production are the primary sustainability concern, rather than the social issues of food distribution, utilization or access. Agriculture has been extensively analyzed as the primary driver of land change and environmental degradation (Ellis and Ramankutty 2008). Much of the research informing this domain of knowledge pertains to the land system—landscape-scale unit of analysis—which is examined through remote observation and at broad scales.

What is sustained and how?

Interventions advocated within this discourse aim at addressing externalities and minimizing the ecological footprint of agriculture as much as possible, often through emphasis in technological innovations that enable improved resource efficiency, conservation and higher productivity (Godfray et al. 2010). For example, the concept of "land sparing," in which agricultural intensification spares land for conservation purposes (Phalan et al. 2011; Tilman et al. 2002), has received some attention in land change science circles.[1] Similarly, the concept of yield gaps is evoked to illustrate the potential to meet global demand on existing agricultural lands through improved resource efficiency and appropriate application of external inputs (Licker et al. 2010; Foley et al. 2011). Other tools and approaches involve improving pre- and post-harvest management to maximize the productivity of agricultural investments.

Global food democracy

Primary problem emphasis and explanations

A different broad-scale discourse on food system sustainability is based largely in the social sciences (e.g., critical sociology, geography and political-economy), and emphasizes transnational economic relationships and the power embedded in them as the primary determinants of the structure and function of the global food system (e.g., Leff 1995; Buttel 1997; Marsden 1997; McMichael 2011). Unsustainable patterns and processes in the food system are perceived as outcomes of these sometimes explicit, but often implicit, relationships of power and wealth between hegemonic corporate transnational actors and producers and consumers in specific locations (e.g., Isakson 2009; Guthman 2007, 2008). Scholars of the political economy of food and sustainability attribute the growing ecological and social externalities associated with the food system to the growing distance and disconnection between producers and consumers, and the political disenfranchisement of these actors in the context of consolidated global supply chains (MacDonald 2007, p. 797). Here, FSS is more of a global political and economic project than an issue of ecology and resource management.

What is sustained and how?

While typically more critical than propositional (Pritchard 2007, p. 8), scholars in this knowledge domain have advocated for restructuring the global food system to reinstate and sustain the social and cultural use values and functions that also form part of the food economy (e.g., McMichael 2011). On a more pragmatic front, solutions from the political economy perspective revolve around efforts in institutional change and food governance (e.g., in the World Trade Organization), and re-embedding and recognizing the *multiple-functionality* of food in trade relations (see, for example, Busch and Bain 2004; Bacon et al. 2008; Auld 2010). However, there is considerable internal debate as to how this is best accomplished. As the power over the global food system has shifted from states to private corporations, alternative trade organizations, certification, standards, ethical foods and other governance tools have emerged to attempt to shape equitable and sustainable outcomes. While there is an internal debate on whether or not proposed solutions are achieving their stated objectives (Auld 2010; Bacon 2010; MacDonald 2007), the expectation is that alternative trade organizations and modes of economic exchange will not only improve social justice and livelihood, but biodiversity or other ecological indicators as well.

The focus on equity and justice within political-economy analyses has led to a convergence with a parallel discourse in civil society—echoed in agroecology and community food security as well—focused on the concept of *food sovereignty*– "the right of peoples and sovereign states to democratically determine their own agricultural and food policies" (IAASTD 2008, p. 5) and *food democracy*—the "ability to make choices about food grown and consumed based on open access to information" (Anderson 2008, p. 596). Thus, a possible solution area is in greater social mobilization, participation, and transparency, not only in local food systems, but also in corporate commodity chains and global food governance.

Distilling core ideas from multiple perspectives

The six knowledge domains that we defined above highlight disparate aspects of the food system: the biophysical interdependencies of production processes, the physiological basis of consumption, the critical linkages between food and community empowerment and social justice, the

[1] There is empirical evidence of forest recovery in some regions where agricultural intensification and economic development have occurred simultaneously (Rudel et al. 2002; Mather 1992, 2001); nevertheless, the viability of land-sparing remains controversial (Perfecto and Vandermeer 2010).

instrumental role of food in economic welfare and development, and the multiple values associated with food and the implications of multifunctionality for food governance. Collectively, these different knowledge domains offer important insights and opportunities for improving food system sustainability, as we have highlighted in Table 1.

Nevertheless, it is also clear that the fragmentation of approaches can produce contradicting conclusions and strategies regarding FSS. For example, promoting the intensification of production through biotechnological advances in seed technology may potentially improve nutrition outcomes and possibly land use by impeding further deforestation in tropical regions (Tilman et al. 2002). Such an intervention might be considered unnecessary or even entirely inappropriate, however, from the perspective of agroecology (e.g., Altieri and Rosset 2000), and runs counter to the concerns of disempowerment and corporate consolidation in food systems voiced by critical theorists and CFS activists (Howard 2009; Sassenrath et al. 2008; Clapp 2003). Furthermore, there are potentially critical problems across scales: while globally, food production and the reliability of harvests might increase from specific technological advances in agriculture, at the local or community scale there are risks of disenfranchisement, increased poverty or decreased access to food technologies that may run counter to sustainability efforts from a perspective of CFS. Currently, these concerns are voiced within specific intellectual knowledge domains and are often dismissed as ideological (as for example, we see in the debate over genetically modified organisms in agriculture), impeding a constructive debate on possible pathways forward. Our challenge is to identify system attributes that speak to these diverse concerns, yet are sufficiently flexible and sufficiently well-defined that they can be used to derive valid indicators to represent them in any specific context.

Undergirding the disparate framings of food system challenges and solutions are some common themes. Translating these themes into systems language can provide some insights into potential points of agreement over the systems attributes most likely to be associated with FSS. Considering the system attributes summarized in the section Generic Principles of Sustainability that other scholars have considered essential for enhancing system resilience and/or achieving specific management objectives, we find the following five attributes particularly salient to the FSS goals of the knowledge domains reviewed above: diversity, modularity, innovation, congruence (encompassing overlap of institutional and ecological structure), and transparency (modified from Walker and Salt's explanation of social capital as building trust, social networks and leadership). Among the other proposed attributes, we have excluded ecosystem services, which are considered to be a food system outcome in Ericksen's (2008) framework, and ecological variability, which is among the things to which a food system, in particular, must be resilient.

We find that elements of these system attributes are echoed in the diversity of perspectives on FSS we have reviewed, although the manifestation of each attribute changes according to the context, analytical approach, and scale of analysis (Table 2). Rather than consider the different ways in which these concepts have surfaced in the literature as indicative of conceptual weakness, we consider this diversity an asset for FSS analysis. Essentially, while the indicator of each concept may change contextually and across scales, its systemic function and thus contribution to FSS is retained. Most important, these system attributes to focus on the characteristics of food systems that shape critical ecological, social-cultural, political, and nutritional outcomes. Together, they define the signposts of the *pathways* towards the normative and ever-evolving ideal of sustainability. While the temptation is always to state that sustainability *is* a particular constellation of activities, beliefs, strategies or outcomes already existing today, we argue that in the face of considerable complexity and high uncertainty, a more constructive approach is to identify and promote undergirding system attributes that can guide us in conceptualizing food system choices adaptively and iteratively. We describe each of these system attributes and their support below.

Diversity

Diversity is a central focus of agroecological approaches, where biodiversity plays a critical role in ecosystem processes necessary for agricultural production, and enhances the capacity of the agroecosystem to respond to shocks and stress (Altieri et al. 1998). Diversity has obvious implications for individual food security: a diversified diet supports the intake of an array of macro- and micro-nutrients that are necessary for supporting human biological functioning. Discourse focused on human economic welfare also has shown the importance of households having access to a diverse array of food sources, distribution channels and incomes to achieve food security outcomes (Ellis 2000). Diversity can thus refer to the number and configuration of distinct species, organizations, institutional arrangements, activities, and people involved in the system.

The various uses of diversity with respect to different components of food systems draw attention to the scalar complexity of food systems. The scale (or organizational level) of assessment will influence the normative decisions about how to manage diversity. For example, smallholder farmers may make decisions about managing species diversity in order to enhance nutritional diversity, or to

Table 2 Meaning of attributes across knowledge domains

	Diversity	Modularity	Transparency	Innovation	Congruence
Individual food security	Dietary	N/A	Nutritional content, policy development	Food technology, biotechnology	Maximized food utilization
Community food security	Food sources, actors	Self-determination	Food content, price, source	Local governance, distribution networks	Culturally appropriate food source and content
Human economic welfare	Livelihood	National supply	Resource ownership, knowledge	Private–public partnerships, biotechnology, agronomic improvements	Scale, cultural and economically appropriate technology
Land change	Biological	Integrity of specific ecosystem functions	N/A	Private–public partnerships, biotechnology, resource efficiency	Respecting planetary biophysical boundaries
Agroecological integrity	Genetic, Agro-biological	Farm self-sufficiency, autonomy	Knowledge, technology, genetic material	Farmers' knowledge and experimentation	Ecological synergy and reliance on ecological processes
Global food democracy	Values, functions, actors	National and local sovereignty	Resource allocation, corporate influence, food content	Governance arrangements, alternative economic institutions	Institutions respect multi-functionality and rights

reduce income variability. This decision, however, is set in the context of the availability and access to markets and off-farm sources of food and capital, which often bind farmers to distant locations and a smaller range of production options. For a geographic region and associated population, reliance on a diversity of economic sectors and food sources may also have strategic value, particularly in relation to the management of idiosyncratic shocks such as localized drought (Hodbod and Eakin 2015). In these distinct contexts and scales, diversity plays a key role in the sustainable function of food systems: it diminishes the risk that any shock or stress will undermine food security, and enhances the flexibility and adaptability of food systems in the face of the high uncertainty and considerable interconnectivity that characterizes the world food system (see Fraser et al. 2005). Of course, diversity is not always beneficial or appropriate at all scales of analysis and maintaining diversity entails costs and tradeoffs. Further research is needed to better understand the shape of the "value function" of different indicators of diversity in relation to food system sustainability (c.f. Bausch et al. 2014).

Modularity

The importance of grounding food system sustainability in the specific localities of consumers and producers in the frame of community food security, the need to improve the interconnectivity between farmers' knowledge, management and local ecological processes in discourse on agroecological integrity, and the strong critique of the loss of social participation brought about by industrial consolidation in the domain of food democracy all speak in different ways to the need for a more disaggregated, self-reliant and locally-connected food system. But the term "local" as a system attribute is misleading, implying an amorphously defined spatial scale rather than connectivity, self-reliance, and control. The systems concept of *modularity* captures the essential intent of debates about "local" and "global" in these diverse discourses. In system terms, modularity refers to the manner in which components of a system are linked, and how these components may be disaggregated. Modularity implies that a system is characterized by nested and networked structures, where specific sub-units of a system have relatively greater internal integration than external integration, and where units can be combined in complementary and to some extent substitutable ways (Schlosser and Vagner 2004, pp. 4–5). Modularity is considered an essential form of system structure and necessary for system evolution and change.

In relation to a food system, it implies a reasonable ability of any community, country, or region, to adapt to changes in the food system relatively autonomously to maintain and satisfy food security objectives. At the farm level, the concept implies a capacity to generate inputs and cycle resources within the farm, without negating the benefits of resource exchange among farm units and the regional or global economy. In the context of food system management, modularity speaks to the potential benefits of food policy councils, or other local governance bodies, to develop food policy appropriate to local conditions and needs, while still complying with national regulations and standards (Pothukuchi and Kaufman 1999). For communities, modularity could imply the ability of specific subpopulations to organize their own food sources (e.g., a community garden, or CSA) and distribution networks (a co-op or food barter network), while still maintaining significant engagement with the broader food system through, for example, shopping in national supermarket chain stores or purchasing commodities imported from distant locations.

For national governments, modularity implies maintaining a diversity of capacities for food provisioning and access without resorting to autarky or the failed policies of import substitution of past decades. The 2007–2008 global food price crisis, for example, highlights the potential importance of maintaining alternative global *and* local market networks and modes of food production and exchange should primary commercial channels fail to satisfy food security needs. This balance between global connectivity and local self-reliance and salience has been signaled as critical for food system sustainability by others—for example, in relation to the concept of connectivity (Fraser et al. 2005) and cross-scale feedbacks (Sundkvist et al. 2005).

Transparency

Food systems are by definition anthropocentric, designed to meet human needs. They are also constructed within societies governed by formal and informal rules, rife with power dynamics, economic disparities, and competing social concerns. The CFS and food democracy discourses discussed above foreground the political and justice aspects of the local and global food system as core challenges for its sustainability. In addition, the food sovereignty movement and aspects of the discourse on human economic welfare are concerned with defending farmers' access to and control over key assets for livelihood security, and the ownership and maintenance of the knowledge and skills necessary for food production (i.e., IAASTD 2008). Frequently *participation* is declared to be a fundamental principle of any sustainability process and is widely advocated in food sovereignty discourse. Participation however has not always achieved its intended function of enhancing equity and procedural justice, and can be subject to the same issues of manipulation and exploitation that it is designed to address (Lélé 1991; Kirwin et al. 2013).

Thus rather than arguing for "participation of all relevant actors" we suggest that a foundation for a more just and equitable food system can be potentially addressed through enhanced *transparency*—defined here as accessibility of "timely and reliable economic, social and political information" (Bellver and Kaufmann 2005, p. 4) through the food system. Transparency is not simply about making information and knowledge available, it also implies that the information and knowledge are of a quality that can be constructively applied: transparency encompasses values such as access, comprehensiveness, relevance, quality and reliability (Vishwanath and Kaufmann 2001). Transparency, as a guide in a pathway to sustainability, aims to provide a baseline guarantee that the knowledge, values, goals and other criteria used in food decision processes are available for all actors to review. This process of public access and review builds social trust, enhances accountability and forms a core component of social contracts. In the context of international development, scholars have argued that transparency is an essential component of democratic processes, providing a foundation for the provision and defense of basic human rights (Sen 1999). In the contexts where such actions are permitted and institutionally supported, different social actors can choose to challenge decisions that affect their food security. Also, if they have adequate agency, they can choose not to consume, purchase or interact with elements of the food system they do not support (Morgan 2010). While there are numerous conditions that bear on the ability to act ethically as an individual, community or society in relation to food, access to adequate information and knowledge is one essential precondition.

Innovation

Innovation, as a system attribute, is somewhat problematic in that it reflects more of an outcome than a descriptor of system structure in and of itself. Nevertheless, we include it here because of its prominence in the FSS and social-ecological system literatures, and its clear importance in the maintenance and evolution of food systems globally. Innovation does not only refer explicitly or narrowly to technology, but rather the creation and spread of new ideas and knowledge throughout society (Westley et al. 2011). Innovation is considered essential in complex adaptive systems as an attribute that permits evolution and change as external conditions also change. Innovation has a long history in sustainability science and practice (Ely et al. 2013) and is strongly featured in perspectives on FSS. The capacity for scientific and technological innovation to reduce the ecological externalities of agriculture and to increase economic opportunity is featured in ecosystem service and human economic welfare knowledge domains (i.e., Sassenrath et al. 2008); the discourse on agroecology integrity puts equal emphasis on the innovative capacities, experience, and knowledge of farmers in resolving the local environmental challenges they face on the farm (IAASTD 2008). Community food security approaches focus on procedural and institutional innovation:

alternative networks for food production and exchange arising from the self-organizing capacities of concerned citizens.

In research on innovation for sustainability, scholars have put forth the idea of "grassroots social innovation" (Kirwin et al. 2013; Smith and Seyfang 2013) as a necessary element of efforts to enhance sustainability. Whereas innovation is often associated with the entrepreneurial contributions of investments in large-scale science and technology, grassroots social innovation refers to creative disruptions in social practice and process, or as Smith and Seyfang (2013) state, "how to do sustainability." Such social innovation emerges from the interaction of a diversity of social actors, working collaboratively in problem-solving. Nevertheless, innovation is conditioned not only by the existence of social spaces and capacities for collective action (see, for example, Feenstra 2002), but also sustained financial support to realize the potential to contribute to sustainability transformations (Kirwin et al. 2013).

Congruence

Congruence, or "fit," among resource institutions and local conditions is thought to enhance their capacity for persistence over time (Cox et al. 2010). Similarly, the ability of experienced farmers to match agricultural practices to the limitations and potential of their resource base is the foundation of agroecology (IAASTD 2008). Agroecologists thus argue for enhanced congruence and synergies between agricultural processes and practices, and the ecological processes at play in the broader ecosystem (Scherr and McNeely 2008). Many popular advocates of FSS, drawing on the political-economy arguments presented in the discourse associated with food democracy, often present the distortions imposed by the food industry as "unnatural": the disjuncture between the biological processes of animals, humans and ecosystems and the demands of industrial capital (e.g., Pollan 2006; see also Goodman and Watts 1997).

Congruence is implicit in individual food security perspectives, with the emphasis on understanding human physiology to ensure that diets better support essential biological functions. In the community food security literature, congruence implies the formation of food distribution systems that are compatible with local needs, cultural preferences and community practices. Here, congruence indicates compatibility with community identity, and presupposes the capacity of a community to articulate its needs, concerns and demand for food in specific political-economic contexts (Block et al. 2011).

Making congruence an explicit principle of food systems may serve to align human and ecological needs flexibly and adaptively across diverse scales. Like other resource regimes, food systems are characterized by the interplay of various social and environmental institutions, often operating at multiple scales and with competing interests (Ericksen 2008). These institutions overlay and connect across space disparate biophysical contexts and ecological systems. In this context, the assessment and design of sustainable food systems must seek to increase "multiple reinforcing gains" by supporting mutually beneficial processes rather than maximizing a single outcome or minimizing tradeoffs (Gibson 2006).

Discussion and conclusion

We recognize that our definitions of specific knowledge domains are in some senses idiosyncratic; we intentionally limited our discussion of some of the finer nuances in the diversity of perspectives on this complex topic to create schemas of each knowledge domain, while acknowledging that these domains have porous and fuzzy boundaries. Nevertheless, we feel that these knowledge domains do encompass a significant part of the wide-ranging literature on aspects of FSS. Our review highlights that these perspectives may have more in common than would be expected from the disparate epistemological and disciplinary contributions associated with each domain. Instead of focusing on the critical, but often polarizing and paralyzing debates on the appropriate means to achieve FSS, we highlight the system attributes that are recognized as playing critical roles in FSS across diverse discourses (Fig. 1). The fact that these attributes continually emerge (albeit embedded in an alternative language or terminology) in discussions of FSS in diverse contexts is indicative of both their theoretical and empirical utility (i.e., Foran et al. 2014; Fraser et al. 2005; Kirwin et al. 2013; Hamm 2009).

The next step is to empirically validate and test the principles we propose in distinct contexts of FSS interventions. First, in any given context, these system attributes can translate into the identification of specific indicators, appropriate for the scale and context of analysis and decision-making. Such a process requires interrogation of the meaning and function of each attribute in that context, and, more concretely, a theorization of the specific relationship of any selected indicator to the general overall goal of a food system that achieves universal food security while enhancing social justice and equity and environmental integrity. Multicriteria decision analytics and complex system analysis are tools that are often used in sustainability science and require far more use and application in food system decision-making than they currently receive (see Bausch et al. 2014; Stirling 2010). Such tools

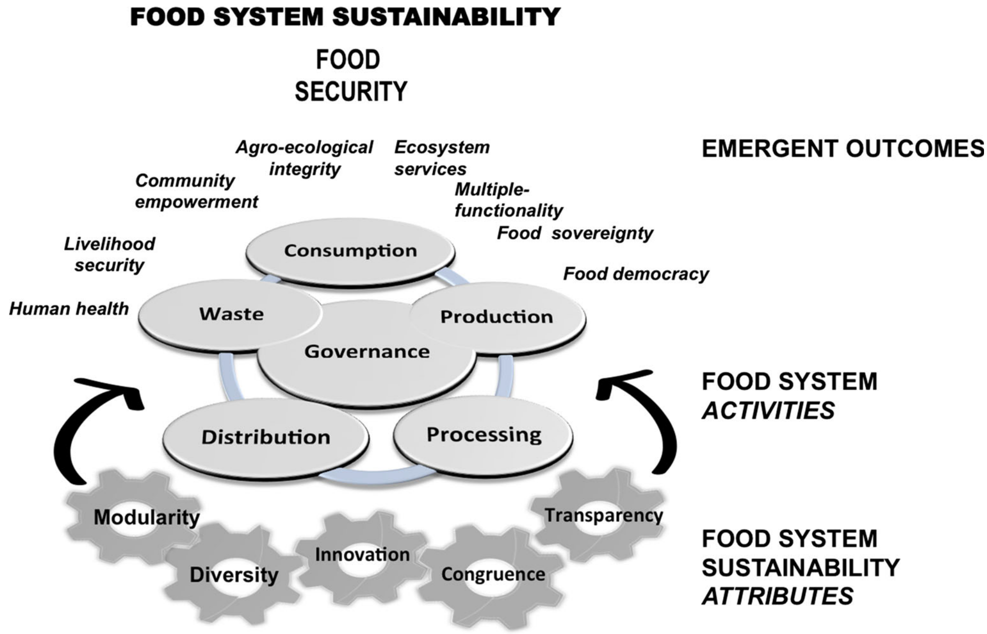

Fig. 1 Attributes of FSS in support of food system activities, leading to emergent outcomes

not only allow decision-makers to evaluate the implications of an intervention on other system elements and interactions, but also to specify the expected relationship—the *value function*—between any particular indicator (e.g., "dietary diversity") and the ultimate outcome desired ("food system sustainability") (see Eakin and Bojorquez-Tapia 2008).

Additional areas that require further exploration are the weighting and prioritization of attributes and the relationships among attributes within and across scale. For example, if a food system intervention were proposed for a community, should the attributes be weighted differently than if an intervention were proposed for a country or landscape? Maximizing agro-biodiversity in a single small farm plot may, for example, take capacity away from more critical priorities (e.g., livelihood security) at that scale. However, biodiversity is clearly a priority at the regional and global scales. Are there some attributes—for example, modularity—that only make sense at a particular level of social or ecological organization and complexity? More critically, are there specific attributes that are *essential* at a particular scale of analysis, such that if this attribute is absent or diminished, the system as a whole unravels completely?

Nevertheless, while some attributes may not necessarily be priorities or even be functionally relevant at a particular scale of analysis, the pursuit of any sustainability outcome should not run counter to any of the principles. A process that is designed to enhance human welfare at the household level (via biotechnological innovation, for example) should not operate at the expense of transparency or social-ecological congruence. These attributes are only broad parameters in pathways towards sustainability: any explicit effort to enhance food system sustainability will also need to engage in an explicit and likely iterative normative process of defining the specific desired outcomes for particular places and peoples, a process that we argue is facilitated by a conscious attention to the attributes we propose here.

Far more empirical research is needed into the cross-scalar, networked and potentially non-linear implications of the pursuit and application of FSS interventions. What, for example, are the landscape-scale and agroecological health implications of a concerted effort to increase the diversity of food distribution channels locally, particularly if such efforts entail increasing the demand for local production? How might increased transparency in international food processing and distribution activities affect consumption patterns among affluent consumers, and thus indirectly the demand placed on agricultural livelihoods and agroecological resources elsewhere? We believe that attention to the system attributes we have identified would help communities, corporations, governmental and non-governmental actors evaluate the systemic implications of their decisions and actions. Nevertheless, because of the globalized, interconnected and networked nature of contemporary food systems, it is nearly impossible to anticipate all the potential consequences of any action taken.

While the risk of negative and undesirable outcomes is always possible and should be expected, we should also expect that significant synergies may occur when these attributes are considered at different scales: enhanced transparency and modularity might lead to innovation; diversifying food access and distribution channels might lead to new interest in ecological conditions of production and thus enhanced social-ecological congruence.

A significant challenge for managing food systems for sustainability is the differential time frames in which the beneficial functions of these system attributes can be observed. The benefits of agrobiodiversity, for example, at the regional and global scales are realized over time, as society struggles to respond to emergent problems with pests and plant disease, and the limitations of the existing agricultural gene pool are acknowledged. The benefits of dietary diversity can be immediately observed in terms of human health outcomes, yet it would be erroneous to aim for a short-term fix that enabled such health outcomes to be realized at the expense of investments in the longer-term preservation of global agro-biodiversity. Such interactions among short-term and longer-term processes and dynamics are fundamental to system science and critical for understanding the future of the food systems.

The five attributes we have identified as central to the structure and function of systems supporting FSS are likely not the only relevant factors that must be considered. We expect that other scholars may take issue with the specific formulation and labeling we have given to the attributes we have identified. Nevertheless, our ultimate aim is to add our voices and contribution to those who have advocated for a systemic perspective on food and agricultural sustainability and to argue for a focus on critical concepts in the process of developing interventions to enhance FSS. The five principles we propose are supported in much of the existing literature; their systematic application requires empirical testing and evaluation. We look forward to that process.

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