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ISSUES IN BRIEF

Agricultural Diversity Across Scales:

Key to Building a Resilient Global Food System

John Patrick Casellas Connors is broadly trained as a human-environment geographer. His research addresses the social and political dimensions of environmental management programs and food systems. Using a variety of qualitative and quantitative research methods, he explores the ways that humans understand and transform their environments and ultimately are affected by these changes. Currently Assistant Professor in the Department of Geography at Texas A&M University, he was formerly a Post-doctoral Associate at the Fredrick S. Pardee Center for the Study of the Longer-Range Future.

John Patrick Casellas Connors

The ways in which societies produce and acquire food profoundly impacts humanity. The advent of field agriculture, the domestication of livestock, and the mechanization of planting and harvesting have all altered the paths of human history. Likewise, the emergence of global trade networks — such as the Columbian Exchange, which brought New World goods across the Atlantic and vise versa — have expanded the availability and variety of foods around the globe. Over the past century, the widespread availability of agricultural fertilizers, increasing mechanization, and new hybrid varieties of crops have boosted agricultural yields and significantly reduced labor demands in agricultural fields. The establishment of new international trade agreements and improvements in food transportation and storage after World War II further extended the trade in food products across great distances. These changes in agricultural production and food distribution networks have supported an ever-growing human population and have contributed to improvements in global food security. Global food production has outpaced population growth, which has more than doubled since 1970, and it has done so while cultivated areas have increased by just 12 percent over approximately the same period (FAO 2011).

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Even as agricultural yields have increased, major changes have occurred in the ways that people access and consume food products. Much of the global population was involved directly in agricultural production at the beginning of the 20th century; by the late 1990s, it was 40 percent and today only 27 percent of global labor is employed in agriculture (ILOSTAT

2018). Furthermore, continued economic development and expansion of global markets has shifted many regions from subsistence production to commercial production. Subsequently, farmers increasingly produce for global markets. These shifts in global food markets have changed access to food supplies, contributing to greater reliance on imported commodities, and increased consumption of processed and fatty foods (Popkin, Adair, and Ng 2012).

Overall, these changes in the global food system, combined with other efforts, particularly foreign aid and relief programs, have decreased famines and helped increase global food security. Nonetheless, there is growing concern that this ongoing re-organization of the global food system may increase vulnerabilities in new ways and limit the options available for adaptation to climate change in the future. Of particular concern are wide-scale losses in animal and crop diversity and increasing geographic concentration of large-scale production systems. Just 74 crops provide more than 90 percent of the world's calories, and the FAO has expressed concern over the extensive loss of genetic diversity in crops over the past century. In addition to these changes in how and where food is produced, fewer nations and companies hold an ever-increasing share of various components of the supply chain (see Table 1).

Table 1. Contribution of globally important crops to global calorie intake and main sources of those crops.

Crop	Proportion of Global Calorie Intake	Top-Producing Region	Percentage of Production from Top Region
Rice	19%	China	28%
Wheat	18%	China	18%
Maize	5%	United States	36%
Potatoes	2%	China	26%
Soybeans	2%	United States	35%
Cassava	1%	Nigeria	18%
Sorghum	1%	United States	19%
Sweet Potatoes	<1%	China	67%
Yams	<1%	Nigeria	67%
Plantain	<1%	Uganda	24%

Source: FAOSTAT (accessed May 2018)

This ongoing transformation presents a fundamental contradiction of our current food system. On one hand, many people around the globe have access to a greater variety of foods than ever before, yet the increasing number of options on supermarket shelves have occurred alongside an increasing homogenization of our production systems. The genetic diversity of the world's crops and livestock are eroding even as producers increasingly gain access to the world's markets and food supplies become more diverse for the average consumer. Through these processes, consumers in different locations increasingly depend upon food supplies from common sources, generating new shared vulnerabilities among the world's populations. As global markets bring products from around the world to consumers, producers and consumers are susceptible to market responses to changes in supplies and prices in distant locations. This paper discusses these emerging vulnerabilities in the global food system and the role of diversity in supporting food security across scales, particularly in the context of global climate change. The paper highlights how our global food system has managed to enhance food security and the variety of foods available to consumers while simultaneously eroding diversity at global scales, and it explores the consequences of these changes for the global food system.

A Systems Perspective of Food Security

Globally, there has been a major reduction in the overall proportion of people suffering from food insecurity and malnutrition, dropping from 14.7 percent in 2000 to 11 percent in 2016, yet there are still an estimated 815 million people globally that continue to suffer from malnutrition (FAOSTAT 2018). This gap persists alongside the vast gains in per capita food production globally. Despite tremendous strides, more work is needed to achieve global food security, or "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit 1996).

Although food supplies have outpaced changes in demand, the benefits from these increases have not been equally distributed around the world, and malnutrition continues to be particularly high in low income nations. These inequalities demonstrate the shortfalls of supply side and market-based solutions to global food security. Even when food supplies are abundant, this may be inadequate to ensure food security for populations that do not have the financial or other means to access these food supplies (c.f. Sen 1981). Increases in production alone will be insufficient to ensure food security around the world amidst climate change. Many practices are involved in the process of bringing food to consumers, and all of these influences will need to be resilient to climate change in order to ensure food security at all times.

Supporting food security into the future requires attention to the various social, political, and economic processes that shape outcomes in the availability, accessibility and utilization of food under changing environmental conditions — factors that shape how food is produced, distributed, and accessed are collectively referred to as food systems (Ericksen 2008, Hodbod and Eakin 2015). In an increasingly interconnected food market, local losses from extreme events or long-term climate change will have impacts around the world. Likewise, conflicts, trade agreements, or changes in local economic conditions may all impact various facets of a food system that contribute to the production, processing, or distribution of food supplies. Ultimately, these impacts on any component of a food system could have implications for food security across scales. In light of these convergent risks, a growing body of research is focused on how ongoing changes in all of these facets of global food systems may produce new threats to food security, and also the ways that these threats may be alleviated.

The Role of Diversity in Food Systems

In ecological systems, diversity is often associated with enhanced productivity, and also produces a range of possible responses to disturbance, increasing the system's resilience to stress (Folke et al. 2004). Losses in diversity, therefore, may make an ecosystem more susceptible to shocks, such as disease outbreaks or climate change. In agricultural systems, biological diversity provides three important benefits: supporting ecosystem services, increasing dietary diversity and nutrition, and enhancing the ability to withstand environmental variability. These three benefits of diversity in agricultural systems are described below.

As in natural ecological systems, each plant and animal species in an agricultural system can support different functions and some redundancy in this functionality may reduce the susceptibility of the system as a whole to shocks. Biological diversity in agricultural systems includes different species of plants and animals, but also different varietals of the same species. Different crops and animals offer different nutrients for both human and animal consumption, and may support important environmental processes, such as pollination, that are necessary for agriculture, as well as animal biodiversity on and off farms. When these functions are not adequately met through ecological processes, then farmers must use pesticides and chemical fertilizers to meet these needs. The basic ecological functioning of a food system undergirds its ability to support food security.

In order to provide food security, a food system must also minimally contain a diversity of products that provide different nutritional benefits, ensuring that all people meet their basic dietary needs. In a completely subsistence production system, basic needs are met by local production of different crops and species, and/or access to a diversity of wild cultivars and animals. Throughout history, people have developed different localized strategies to meet their nutritional needs and to ensure sustained production. Companion cropping approaches have also been widely employed throughout human history, growing combinations of crops together in fields in order to support soil health and nutritional outcomes. Famously, the “three sisters” (maize, winter squash, and beans) were grown in combination in the pre-colonial Americas, providing a complete set of amino acids to consumers, and enhancing nutrient cycling in agricultural soils. Collectively, these ecological and nutritional roles of biological diversity can be classified as functional benefits.

In addition, biological diversity in production systems can support resilience to shocks. Some crops, for example, are better adapted to droughts than others. Known as “response diversity”, this variation in responses to stresses can be important to weathering environmental and economic shocks. For example, pastoralists in Turkana, Kenya are known to keep multiple species of livestock as a strategy to withstand variations in rainfall (Leslie and McCabe 2013) — explicitly to address response diversity and resilience. If drought negatively impacts the reproduction and milk-production among cattle, the pastoralists still obtain milk from camels. Likewise, if a disease spreads among their goat populations, the cattle will likely remain healthy. Such internal response diversity ensures that all resources are not wiped out in the wake of a major shock and supports food security through environmental variability. Similarly, subsistence and small-scale farmers frequently buffer against shocks by growing a diversity of crops that do well under different conditions. Nonetheless, even smallholder farmers are increasingly connected to global markets, and these global markets are transforming the geographies of agricultural diversity.

Reconfiguring Diversity Across Scales

In a subsistence or highly localized food system, diversified production is essential to supporting nutrition and ecosystem functioning, while reducing risk. In a globalized food system, however, producers and consumers no longer rely on diversified production in any one area to support these functions. With access to supplies from global markets, chemical fertilizers and pesticides have largely substituted many of the functional roles of diversity. Most consumers now purchase all or some portion of their diet, allowing consumers to obtain food from other parts of the globe even if production fails locally. Likewise, nutritional needs and dietary diversity are obtained by access to a greater variety of products available through these global markets. Thus, the globalized food system has helped to reduce risk for many consumers, to enhance food access, and to improve dietary diversity, particularly in urban areas.

These transformations in the global food system have increased diversity for consumers, but have coincided with losses in overall global crop diversity (Khoury et al. 2014). Several factors contribute to this loss of agricultural diversity:

- Access to global markets and insurance programs allows farms to focus their production on the highest yielding varieties and approaches to increase their production efficiency rather than resilience.
- Many food processors and distributors demand consistency in their supplies and therefore only purchase a few specific varieties of products from producers.
- Global markets encourage regional specialization as producers must compete with other producers around the world.
- National and subnational policies provide incentives for production of specific items, further contributing to their global competitiveness.

These characteristics of the global food system, along with geographic differences in infrastructure, have led to significantly less diversity in agricultural production at the local scale even as consumers have more choices in food products from around the globe.

Yet global food systems could leverage geographic diversification to achieve some of the resilience benefits that are threatened by loss of agricultural diversity at the local level.

With access to production systems in different parts of the world, consumers are buffered against any shocks to food supplies from a single region. For consumers, this geographic diversification greatly reduces the risks of losses resulting from drought or other hazards that typically only impact a particular region or area. Redundancies in production systems around the globe create opportunities for substituting losses from one region with products from another in global markets. The array of processes described above may drive reduced diversity at local scales, but consumers actually have a more stable supply and greater diversity of food products at their disposal through global markets.

Although this shift in the production and trade of food has supported increases in global food security to date, the potential benefits of geographic diversification may be undermined by ongoing processes of regional specialization. Rather than supporting a broad dispersal of production systems around the world and providing some redundancy in production across regions, production is becoming increasingly specialized, with some crops grown in fewer geographic areas. The increased homogenization and regional specialization of agricultural production is quite apparent for several of the world's most important food supplies. Brazil and the United States, for example, together provide almost all of the world's maize and soy production. Meanwhile, China and India collectively produce nearly half of the world's rice (FAOSTAT 2018).

Concentrating these significant resources in small geographic areas may be increasing the likelihood of large scale crop losses that could have global impacts (Janetos et al. 2017). Climate change impacts on these areas could affect global supplies and prices. Furthermore, large uninterrupted stretches of the same crops or high concentrations of livestock increase the risk of widespread disease and pest outbreaks. Geographic concentration of these production systems also threatens to exacerbate environmental damage as increasing concentrations of nutrient runoff threaten the stable functioning of ecological systems, particularly in aquatic systems. This is nowhere more apparent than in the widespread water pollution emanating from intensive agriculture in the Midwestern United States, which contributes to the extensive "dead zone" in the Gulf of Mexico (Turner and Rabalais 2003).

"...the global food system may be reducing biological diversity in local production systems without gaining the benefits from geographic diversification."

Global trade networks have allowed consumers to access a greater diversity of foods through markets, essentially reducing diversity in local production with diversity from around the globe. This geographic diversity could also support greater resilience of the global food supply if it were dispersed in such a way that food production was spread among many areas that were unlikely to experience losses at the same time. Global production, however, appears to be increasingly concentrated geographically, introducing new risks for food supplies. As such, the global food system may be reducing biological diversity in local production systems without gaining the benefits from geographic diversification. Although consumers have access to greater diversity, that access is through a potentially vulnerable system.

Diversity Beyond Fields

While changes in biological diversity in food systems have an array of potential implications for global food security, these changes have occurred alongside wide-scale transformation of food distribution and processing systems as well. These changes have not only produced new risks for food security through the loss of diversity in production systems but also through loss of diversity in the distribution and processing networks themselves. In general, agricultural supplies, distribution, and processing are undergoing increasing concentration of key resources into the hands of fewer actors (Clapp 2011; Lang 2003). Just three companies control more than 50 percent of the global seed market and six firms control 75 percent of the agrochemical market. In terms of global trade, nearly 75 percent of trade in cereals and soy is controlled by four corporations— Cargill, ADM, Bunge, and Dreyfus (Murphy, Burch, and Clapp 2012). These differences are exacerbated by limited numbers of processing plants for grains and meat that are often controlled by the same corporations, seeking to develop vertically integrated supply chains.

Like the production systems themselves, these structural changes in food processing and distribution may also be susceptible to environmental shocks. For example, natural disasters can disrupt transit networks or key processing centers, affecting global food supplies and prices. If there are a limited number of processing centers or trade routes to supply globally important products (i.e. limited redundancy), then a disruption to one of these nodes will likely have far-reaching impacts. Along with the physical vulnerabilities associated with this consolidation of food systems, economic shocks may also have greater impacts. Because of their large stakes in global food systems, these firms can greatly affect commodity markets with any actions they take. Both internal and external forces that affect these firms could have cascading impacts on global food supplies and market prices.

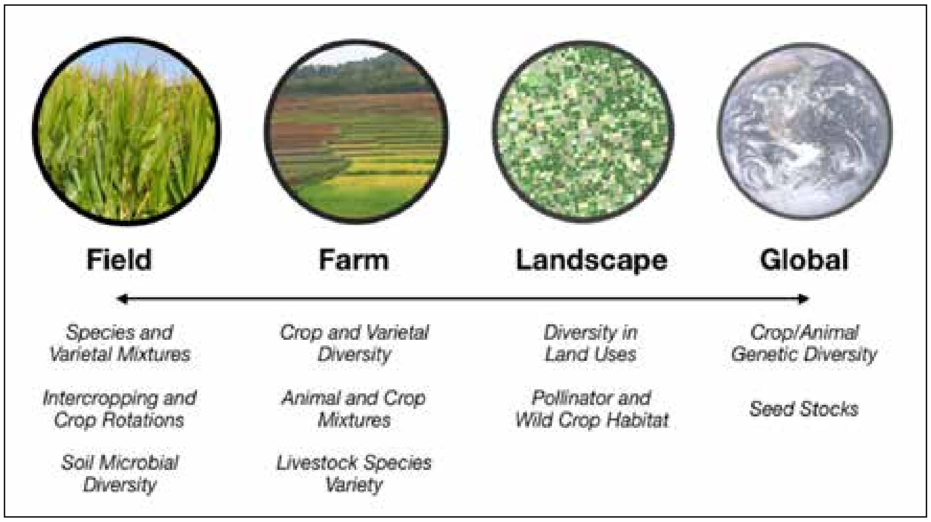
These impacts on prices have implications not only for consumers but for the small scale producers who are also susceptible to shocks in global prices. Food security for many farmers and producers, particularly smallholders in the Global South, is directly tied to these prices, which in turn affects their incomes. Increasing connectivity of markets can increase competition and drive down commodity prices, leaving smallholders to compete with large scale mechanized producers. Despite these risks, agricultural development still remains a major strategy for economic development programs in much of the world, particularly Africa and Latin America (Sanchez 2015). A major concern, however, is that poor farmers will take on greater debt and increase their vulnerability as they increase their reliance on agrochemicals and specialized seeds while also sacrificing the safety net of diversified production systems.

Building Resilience through Diversity

The gains made over recent years to increase food security around the world have been tremendous, but these successes have come with consequences for the biological diversity of livestock and crops. These changes in production systems have emerged in tandem with a consolidation of processing and distribution systems. As a result of this combination, the current structure of the global food system has been greatly simplified in terms of its biological diversity and the number of actors involved in bringing food to consumers. Ironically, this broad simplification of global food systems has brought new variety in products to consumers and has supported increasing access to a stable and varied food supply. Nonetheless, the long-term viability of such a system remains precarious, particularly in light of the likely impacts of climate change.

With regard to climate change, impacts on food security are now likely to extend far beyond the immediate sites of environmental shocks as losses in production in one place may ripple through global markets. The process of geographic diversification and increased yield efficiencies may compensate for some short-term losses, but homogenization of global production systems and their increasing geographic concentrations may also increase the likelihood of widespread losses. Maintaining genetic diversity in crops and livestock offers one important element to enhancing our capabilities to adapt under changing conditions. Throughout history, humans have bred plants and animals for an array of different traits and to thrive in distinct contexts. For example, Peru's incredible diversity of potatoes — estimated to exceed 4,000 varieties — are distinctly adapted to the variable conditions across significant altitude changes in the Andes. Maintaining such genetic diversity could be critical to breeding future plants and animals that can withstand changing climatic conditions and evolving diseases. Enhancing diversity at multiple scales may also provide benefits for further enhancing nutrition and reducing reliance on external inputs. (Figure 1.) Maintaining this diversity at local scales may also help farmers and communities to withstand economic and environmental variations. Nonetheless, for many consumers around the globe, changes in geographic diversity and the structure of trade and distribution networks may be of greatest concern for ensuring food security into the future.

Figure 1. Components of agrobiodiversity across scales



Future strategies to support long-term improvements in food security must be attentive to the variable ways that diversity is produced or eroded across scales and for various components of a food system — inclusive of production, distribution, processing, marketing, and consumption practices. As the global population stabilizes in the coming decades and the threats of climate change continue to mount against food systems, humanity will no longer simply need to make more food, but will need to consider how to ensure global food security through a system that is resilient in terms of its production, processing, and distribution, and which ensures equitable access to all. This will require new institutions and polices that are attentive to how diversity is supported in food systems across scales, and it will require extensive research to understand the risks inherent in our current system and ways to reduce them.

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The Frederick S. Pardee Center
for the Study of the Longer-Range Future

Boston University
Pardee House
67 Bay State Road
Boston, MA 02215 USA

pardee@bu.edu
+1 617-358-4000 (tel.)
+1 617-358-4001 (fax)
www.bu.edu/pardee

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