

Toward resilient food systems through increased agricultural diversity and local sourcing in the Carolinas

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Abstract Biological and agricultural diversity are connected to food security through strengthened resilience to both anthropogenic and natural perturbations. Increased resilience to stress via increased biodiversity has been described in a number of natural systems. Diversity in food production can be considered on the following three levels: (a) genetic diversity as reflected in the range of cultivars which can be selected for production; (b) species diversity, captured through production of a wide range of crops on each farm; and (c) broad ecosystem diversity, described by the diversity of production between farms and within the broader food system. A network of locally based food producers and entrepreneurs provides opportunity for high diversity at each network stage, with increased adaptive capacity and the ability for rapid response to disturbance. We argue that production techniques that use carefully planned diverse plantings, such as biointensive cultivation, increase resilience by increased water use efficiency, yield and nutrient retention while reducing pressure from pests and pathogens. We present a model for a diverse, distributed food system in the North Carolina Piedmont and analyze an existing distributed network by a food hub in South Carolina. Through these models, we argue that a shift in the food network has the potential to increase local food security by having food more reliably available where it is needed and by contributing to local resilience through community economic development. The shift in food

production and distribution systems serves multiple goals: When crop loss occurs, other crops still contribute to overall harvest, reducing net loss. Diverse on-farm production can support a more distributed network of food aggregators, processors, and markets than the current approach of large-scale consolidation. Finally, a distributed food supply network supported with diverse agricultural products can increase resilience by providing access to diversified markets for producers and improved food access to consumers with more food choices, while expanding the need for skilled jobs supporting the regionally based food industry.

Keywords Food resilience · Biointensive · Food hub · Food network · Organic · Agricultural biodiversity · Food security · Agricultural security · Agricultural resilience

Introduction

The term “resilience” has been used in many social, economic, and ecological contexts with varied meanings and interpretations. In its broadest form, the term resilience refers to the ability to recover from or to adjust to change (Gunderson 2000). Uncertainties in an era of rapid change in agriculture have led to uncertainty in the capacity to meet growing food needs. Concerns about chronic malnutrition, environmental degradation, livelihood security, food safety and hygiene, and equitable access raise important questions about how and where food is grown and eaten.

In this paper, resilience is defined as the capacity for a system to absorb disturbance and to reorganize, while retaining system function and self-organizing processes (Gunderson 2000; Folke et al. 2004; Folke et al. 2010). Resilience can be measured by the magnitude of disturbance that can be absorbed before the system is redefined into a different state (Gunderson

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2000). In the case of agriculture and food security, resilience can be considered from the perspective of food availability with a return to a predictable and adequate supply following a disturbance. In this case, disturbances may occur in production (as with the loss of a crop following a plant disease or pest outbreak, severe weather, or climate change), transportation, processing, distribution, and access/supply.

Locally based and controlled food production systems with high diversity can provide opportunities for adaptive capacity through the ability to rapidly respond to disturbance and to changing conditions in production and market conditions (Hendrickson and Heffernan 2002). The prevailing perception is that food production is predictable with a constancy of relationships. As anyone who has been involved with food production, processing, and distribution has experienced, uncertainty in food production and post-harvest handling is common—and risks are high. Adaptive capacity and adaptive management acknowledge that the system being managed will always change, so humans can respond by adjusting the system quickly (Gunderson 2000).

A growing body of evidence highlights the importance of biodiversity for ecosystem functionality (Peterson et al. 1998; Fischer et al. 2006; Kerkhoff and Enquist 2007). Although food and agricultural systems are highly managed, they are still guided by ecological principles through provision of essential natural resources, ecological function, and ecosystem services. Just as with natural systems, biodiversity within food systems can be considered across a range of spatial scales from single farms to larger landscapes. Food system diversity also includes social dimensions such as food distribution and access. Sustaining ecosystem function in agricultural activities is essential for sustaining farm livelihoods and the food supply (Tomimatsu et al. 2013).

Functional redundancy within an ecosystem may increase resilience to environmental fluctuations, facilitating successful reorganization of ecological systems. High response diversity may ensure ecosystem functionality, providing a range of ways to respond to environmental change and uncertainty (Folke et al. 2004). Biodiversity in agricultural systems can improve crop protection and soil fertility through these expanded functionalities (Altieri 1999). Below, we discuss two examples of risks from biodiversity loss, the Southern corn leaf blight epidemic of 1970 and porcine epidemic diarrhea, which demonstrate the negative possible outcomes of genetic uniformity in food systems.

Building on this, the insurance hypothesis for ecosystem resilience through conservation of functional diversity and responsive scale may be transferable to food systems. In the case of food systems, diversity in farm scale and number, diversity of crops, type of market opportunities, and higher numbers of farms equate to high numbers of species that respond differently to external pressures in ecosystems where diversity provides “insurance” if one component of the system declines or is lost. To overcome such risks, species with similar traits may be functionally redundant; if a crop is lost because of high disturbance sensitivity (drought or disease, for example), other crops

will still provide agricultural product (Mori et al. 2013). Some techniques such as biointensive agriculture which emphasize high biological diversity are most easily adaptable to small acreage. A concern can be about yield loss under such production techniques. However, intensively managed biointensive farms can produce yields which are comparable and often greater than conventional methods, while enhancing ecosystem structure and functions such as biogeochemical cycles and pest population controls.

The contemporary food system is built on a complex network of related activities, ranging from on-farm production to harvest and sale to distribution, processing, and marketing, ending with consumer access, purchase, consumption and resource, and waste recovery. Many related factors including environmental, social, and economic disruptions have the potential to contribute both chronic and acute disturbance to all points in this complex system. It is important to consider resilience at all points in the food system, minimizing vulnerability in each individual sector. Therefore, it is crucial to link the shift in food production systems with a shift in the food distribution mechanisms. Indeed, greater crop diversity offers opportunities for more diverse markets, and a locally embedded network of markets for food sale and access may provide greater resilience by insuring multiple points of entry for sale and access if the system is disrupted. As the two models below, North Carolina Central Piedmont Network and the South Carolina Food Hub demonstrate, decentralized models that link producers to consumers provide opportunities for farmers that utilize high-yield, low input techniques such as biointensive and other agroecological techniques a convenient and reasonable access to markets. Since the techniques can be developed both in urban and rural areas on smaller acreage farms, they can reduce the upfront capitalization costs for a start-up farm and also provide access to food related entrepreneurial opportunities and to food for low-income, ethnically and racially diverse consumers.

This paper explores the link between diversity and resilience in our food networks—from production to distribution. We first illustrate risks from loss of biological diversity in food production systems and discuss how biointensive techniques can help overcome such risks. We then discuss two models of food value chains in the Carolinas and how a shift in food distribution mechanisms built on principles of biological diversity can help build food security and community resilience. We also discuss the challenges of establishing such models on the ground and thus offer guidelines for practitioners on how to establish decentralized/local/networked food production, distribution, and access systems.

Food production risks from biodiversity loss—two case studies

The Southern corn leaf blight epidemic of 1970

One dramatic example of crop vulnerability through loss of biodiversity was the cultivation of corn in the USA under

conditions of extreme genetic uniformity for production efficiency. The outcome was the 1970 epidemic of Southern Corn Leaf Blight, causing a crop loss of over \$1 billion (priced at 1970 dollars) (American Phytopathological Society 2015).

Corn leaf blight is caused by a fungus, an ascomycete, *Cochliobolus heterostrophus* (also known as *Bipolaris maydis*, or its name at the time of the epidemic, *Helminthosporium maydis*). The fungus was common across the southern corn production areas, with annual losses of around 2.3 % under normal production. Cultural practices to reduce leaf wetness and maintain general resistance throughout the corn population were the most affordable and consistently effective means of control. Stubble left following harvest was plowed under to enhance decay, with corn production moved to other fields the following year (Levings III 1990; Schumann 1991).

Early in the twentieth century, corn breeders found that greatest yields were produced by progeny from the crossing of two genetically different inbred parental lines (Buckner 2014). Production of seed from defined crosses, however, required carefully controlled pollination and removal of the corn tassels. The detasseling process is very labor intensive and must be done by hand before pollen shedding. A genetic factor was discovered that caused plants to become male sterile, the Texas male-sterile (TMS) cytoplasm (Levings III 1990). This meant that plants used for corn production no longer had to be de-tasseled prior to pollination—a huge economic benefit to the corn industry. By 1970, nearly 85 % of the corn produced in the USA contained TMS cytoplasm.

Genetically, two changes occurred simultaneously in the host (the corn) and the pathogen populations. The corn crop now had the new TMS gene throughout the population, and a genetic change occurred in the population of the fungal pathogen. A new race, named Race T, evolved which had genes to produce a toxin that only affected the TMS plants. The fungus could now complete its life cycle more quickly and was able to infect not only the leaves and husks but also the developing ears.

For disease to occur, three conditions must be met—a susceptible host, a virulent pathogen contacting the host, and an appropriate environment. The genetic uniformity of the corn with the TMS genes introduced the susceptible host. The genetic change in the pathogen, evolved in response to changes in the host genetics, greatly increased the virulence. The weather during the summer of 1970 was warm and wet, ideal conditions for disease to develop. The infection started in early summer in the Southeastern United States. By early fall, corn across the entire east coast and westward past the Mississippi River had become infected, with 80–100 % crop loss in many areas.

The result was near complete loss of the corn crop that year, with a huge economic impact. Fortunately, producers returned to still available non-TMS lines of corn, again requiring manual detasseling. With the return to production of corn varieties lacking the TMS genes, epidemics of this disease have not

returned. However, as current corn production becomes less diverse, similar risks may again become important.

Porcine epidemic diarrhea

Most pork producers raise hogs for specific markets, resulting in limited genetic variability. Breeds and hybrid lines are often selected for uniformity and product predictability, such as size, feed conversion, time to market, and/or meeting the requirements of the integrator or marketing company (Martinez and Zering 2004).

The disease porcine epidemic diarrhea has had widespread and damaging impacts throughout the pork industry. The disease was first confirmed in the USA in April 2013. It is caused by a highly transmissible coronavirus genetically related to strains found in China (Stevenson et al. 2013). This disease can be contracted by pigs of all ages; 100 % mortality often occurs with suckling pigs. The incubation period is only 12–24 h. Symptoms include vomiting and severe diarrhea, frequently followed by dehydration and death. There are no effective vaccines or pharmaceutical therapies for the disease at this time.

The disease is highly contagious and environmentally stable. A tiny amount of material taken from intestines of an infected animal can be highly diluted (diluted 10^{-8}) and still remain infective. Air-borne transmission is under investigation. Trucks and trailers used for dead haul, transport of animals to processing plants, feed deliveries, trash removal and other activities on infected farms have likely been associated with disease spread (National Pork Board 2014).

The toll on the swine industry has been high. Of the 63 million hogs in the USA, about 7 million have been lost to this disease (US Department of Agriculture 2014). Some individual swine farms have lost as many as 30,000 pigs. In response to the rapid disease spread, quarantine measures were put into place in fall 2013. Farm visits were not allowed, and movement of people and materials between farms and processors was restricted and monitored.

Biosecurity measures, isolating one farm from another and preventing movement of infectious material between farms, have been the only effective method for control (National Pork Board 2014). Separation of farms across North Carolina and across the country is comparable to high landscape level diversity with species separation in natural systems, similar to the space between farms and sanitation providing a physical barrier to pathogen movement.

Most hogs are grown by independent farmers, who are producing on contract for sale of the animals to a larger integrator (animal processor). For example, one such integrator has contracts with over 2000 independent farmers for swine production across the USA. The integrators are requiring quarantine between farms as part of the contractual agreement. Many of these independent farmers are small to mid-sized

concentrated animal feeding operations (US Environmental Protection Agency 2015). When compared to production on only a few very large swine farms (>100,000 animals), this distributed national network of independent, smaller farms provides opportunities for implementation of the needed biosecurity measures and physical separation. Farms can be widely spaced across the landscape, reducing potential for aerial transmission, and strict sanitation measures have been effectively implemented with farm isolation. In addition, risk is distributed across the 2000 farmer network, rather than being concentrated in only a few centralized production farms.

This suggests that resilience in the hog industry may be dependent on small farms producing animals independently of each other, rather than depending on large, centralized Concentrated Animal Feeding Operations. It also argues that genetic diversity between growers and by each independent grower should be increased to add potential disease resistance and resilience within the industry.

Biological and Agricultural diversity in farm production

In agricultural systems focused on local market channels, resilience can be enhanced by a diversification of on-farm products as well as by distribution of more smaller farms across the landscape, as suggested by the above two examples (Thrupp 2000). On farms, production risk is distributed across the products being grown for harvest and sale. Each product represents an ecologically functional group, with varied ranges of tolerance for conditions within the production environment. For example, some crop plants may have a wider or shifted range of tolerance for temperatures or available moisture.

Based on observations from natural systems, biological and agricultural diversity can be considered from several perspectives:

On-farm diversity

- Genetic diversity—choice of cultivars, as seen in the previous corn example
- Species diversity—choice of crops
- Complimentary species—intercropping and companion planting to enhance water/nutrient access, stress resilience and yield, and reduce pest and pathogen pressures

Between farm diversity

- Farm separation to reduce the spread of pests/pathogens and other risks, as seen above with swine
- Farm proximity to benefit from shared resources (equipment, marketing networks, etc.)

- Diversity of markets based on diverse crops and production

Some crop production techniques mimic and enhance ecological processes and function within agricultural settings. Biointensive production is an example of one approach which is focused on application of principles of agroecology (Grow Biointensive 2014). Biointensive production emphasizes high crop spatial and temporal diversity via crop selection and multi-cropping practices. Soil is highly managed for fertility and biological activity through an initial deep tillage and frequent carbon and nitrogen additions through green manures and compost. These techniques are often most suitable for small-scale farming and are able to provide product to the local food supply network for sale and distribution. There is also efficient land use and minimal reliance on mechanized equipment. These options are severely limited in conventional agriculture which is dependent on high acreage, uniform mechanized production (Jeavons 2006).

A number of studies in natural systems have shown a correlation between high biodiversity and pressures from pests and pathogens (Janzen 1970; Connell 1971; Wright 2002; Peterman et al. 2008; Terborgh 2012; Bagchi et al. 2014). In some ecosystems, there is a feedback between pest and pathogen populations and biological diversity, with pests/pathogen pressures reduced as individuals of each species become more widely separated with increasing biological diversity, reducing the potential for disease and insect spread.

Production methods which can enhance agricultural diversity such as organic production have been compared to conventional production in a number of studies. Two large-scale meta-analysis studies have suggested that high acreage crop yield with organic production is generally lower when conventional methods are used. However, the yield differences between the two methods varied widely and were highly contextual, differing between crop groups, regions, site characteristics, and cropping techniques (di Ponti et al. 2012; Seufert et al. 2012). In addition, organic production can be done in large acreage monoculture, minimizing biodiversity (Mission 2014).

In contrast, some techniques that are most easily adaptable to small acreage, intensively managed farms can produce yields which are comparable and often greater than conventional methods, while enhancing ecosystem structure and functions such as biogeochemical cycles and pest population controls. Biointensive techniques with high density diverse plantings have shown a 25–400 % increase in production with improved water use efficiency, as for tomato, basil, and brussels sprouts (Jeavons 2001; Jeavons 2006; Bomford 2009; Grow Biointensive 2014). In another study evaluating yield of nine onion cultivars, 45 kg/10 m² were produced with conventional practice compared to 160 kg/10 m² with biointensive techniques (Moore 2010). In addition, energy efficiency was improved from an energy efficiency ratio of

0.9:1 with conventional tillage compared to 51:1 with biointensive production—meaning 51.5 cal of food were produced for 1 cal used for production. With biointensive production, most of the energy input was from direct human input (renewable) rather than from fossil fuels (Moore 2010).

High biological diversity is a characteristic of biointensive production, with at least 13 different types of plants grown together, including food for local consumption, food for sale, and compost crops. One farm in California, Woodleaf Farm, grows over 200 different crops on 3 ha of land with 7 ha in woodland and meadow, using similar cultivation techniques. This farm notes anecdotal evidence that populations of beneficial insects have increased while pests and pathogens are minimized (Woodleaf 2014). Enhanced productivity, water use efficiency, creation of unique microclimates, and pest/pathogen management are also attributed to high crop diversity (Woodleaf 2014).

Soil management in biointensive systems is directed toward enhancing ecosystem processes (e.g., nitrogen fixation, mineral immobilization) which are associated with soil fertility (Perrings et al. 2006; D’Haene 2012). Common practices include double-digging soils (loosening two layers of soil) to a depth of 0.7 m with annual amendments of cured compost and green manures. Communities of bacteria acting synergistically can suppress plant pathogens, promoting plant growth and crop production (Kinkel et al. 2011; Mendes 2011; Hadar and Papadopoulou 2012; Gaiero 2013) and regulating carbon flux (Fitter et al. 2005). Biologically active soil amended with organic materials will also provide ecosystem services by retaining water in soil, regulating biogeochemical processes, increasing cation exchange capacity to enhance nutrient retention and plant availability and reducing material loss from the production beds (Cooperband 2002).

Environmental benefits with biointensive and similar types of agricultural production include (Jeavons 2001):

- Carbon sequestration and soil renewal through production of compost plants
- Closed system for biogeochemical cycling (N, P, K, micronutrients, water)
- 67–88 % reduction in water consumption
- No use of synthetic fertilizers, no N₂O (a potent greenhouse gas and precursor to tropospheric ozone) emissions
- 94–99 % reduction in energy needed per unit of production
- Increased genetic diversity through open pollination.

From 2007 to 2012, average farm size in the USA increased from 418 to 434 acres, while the number of farms declined by about 100,000. Significantly, the number of small farms, those most suitable for biointensive and similar types of production (1–9 acres) declined nationally from 232,849 to 223,634. The number of large farms (≥ 2000 acres) increased

from 80,393 to 82,207 during the same period of time (US Department of Agriculture 2014). These trends suggest that agricultural production in the USA has the potential for decreased resilience, as farming becomes more consolidated into large acreage operations growing a small number of crops on each farm.

Biointensive and similar practices have the potential to greatly enhance the adaptive capacity of the food production network, increasing crop/product diversity, while shortening the supply chain from production to consumption. They also have the potential to increase productivity per unit area, while protecting and enhancing ecosystem health.

Resilience in economic and social systems through local food networks

A proposed model for the North Carolina Central Piedmont

Through more diversified agricultural production, as described above, greater resilience can also be attained within locally based food systems and associated economies. A distributed and regional network of small-scale aggregators, processors, distributors, and markets has the capacity to make venues for sale of farm products more accessible to small farmers, especially as they diversify their crops. Greater crop diversity offers opportunities for more diverse markets, especially in specialty and ethnic foods. A distributed network can foster regional job growth within the food system and enhance food access to underserved communities. A distributed network of producers, buyers, processors, and consumers that share adjacency also have more opportunity for sharing information and knowledge such as technical advice, information about buyers and markets, new regulations, market opportunities, and new innovative practices. The distributed network can also support current models of centralized markets by consolidating products from small growers into larger quantities for sale/purchase.

Currently, large aggregators leave little room for small producers who cannot meet minimum quantities required for sale. They also usually require a substantial supply of single, uniform crops, creating a disincentive for on-farm crop diversification. In contrast, small producers have found much of their success by selling directly to consumers through farmers markets and Community Supported Agricultural (CSA) models (Low and Vogel 2011). Among US farmers, in 2012, nearly 8 % of farms sold primarily through direct-to-consumer (DTC) markets, including farmer markets and CSAs while another 30 % used DTC marketing in addition to other venues. The number of American farms with DTC sales increased by 17 % and sales increased by 32 % between 2002 and 2007; however, between 2007 and 2012, the number of farms with

DTC sales increased 5.5 %, with no change in total DTC sales. That DTC sales did not increase may be a reflection that consumer demand has been met (Low and Vogel 2011).

Effectiveness of these direct market outlets for small farmers can be place-based and the cost of marketing can be high. Additionally, most farmers benefit by having a combination of sale approaches and types of crops to market. As in other industries, market diversification in the produce business is a means to minimize risks—a diversity of market connections supports a financially sustainable farm enterprise (Izumi et al. 2010; Vogt and Kaiser 2008; US Department of Agriculture 2010).

Additionally, the food system benefits by having a diversity of local and global channels for the distribution, storage, and value-added processing of food through an increased base of skilled labor. In the event of a disruption (natural disaster, economic collapse, contamination of a supply chain), there are multiple alternative channels that can supply a population's food needs, including supplies closer to communities needing food. Disaster notwithstanding, the resilience of the local economy may be increased because of the geographically-linked, skilled jobs that are created: farming, logistics, marketing, storage and distribution, value-added processing, equipment maintenance, input supplier, and many other jobs that cannot be outsourced to non-local entities. In the current national food system, where food is grown and harvested several states away and aggregated by large, centralized corporations, these jobs and skills are not available locally. An increase in non-transferable, geographically dependent, skilled jobs increases the resilience of the local economy immediately.

Opportunities/current challenges in the North Carolina Piedmont

According to the the North Carolina Commission on Workforce Development, *State of the North Carolina Workforce* report (2007), rural areas of North Carolina continue to lose employment opportunities, and “middle jobs” that supplied a family-sustaining wage for workers with little formal education are disappearing rapidly. The median family income in North Carolina is \$46,450, substantially below the national median of \$53,004, with 17 % of the population living in poverty. Median incomes in rural counties are often 10 % or more below the state median (U.S. Census Bureau 2014). Central North Carolina is also challenged by many communities having limited access to food. North Carolina is ranked 10th in the nation for degree of food hardships, and Greensboro, North Carolina in the North Carolina Piedmont, has been identified as the most food-limited metropolitan area in the nation (Food Research and Action Center 2015).

For many small farmers in the Piedmont region of North Carolina, farm income is a supplemental, yet crucial, part of

their household economy. In 2012, about half of the people identified as farmers (50,218 individuals) in North Carolina by the US Department of Agriculture did not farm full time. Of those, 19,563 worked more than 200 days off farm (US Department of Agriculture 2014). For many of these families, small farm operations provide much needed household income to supplement off-farm, low-wage job earnings (US Department of Agriculture 2014). Small farming operations also present economic opportunities for partially- or fully-retired growers, as well as opportunities for beginning producers interested in scaling up to full-time farm businesses. When farmers utilize high-yield, low input techniques such as biointensive and other agroecological methods, farming businesses can be developed in both urban and rural areas, as smaller acreage farms (typically 0.5–5 acres) are proving their viability. Reduced land and equipment requirements also reduce the upfront capitalization costs for a start-up farm.

One of the barriers that small farmers experience when developing a farm enterprise is identifying convenient and reasonable access to markets for the sale of their products. Generally, individual small growers do not have the physical infrastructure (e.g., cold storage), product volume or market access to sell to institutions or buyers that can pay a fair wholesale price and provide a consistent market for their products.

There is room for growth and diversification in the local food sector. According to the US Department of Agriculture, in 2004 North Carolinians spend \$35 billion per year on food (US Department of Agriculture 2004, Center for Environmental Farming Systems 2013, 2014a, b). Although spending on local foods is difficult to track, CEFS is encouraging North Carolina consumers to spend at least 10 % of their food dollars on locally produced food. The North Carolina 10 % campaign is in the third year of its promotion to bring local foods spending closer to this benchmark. At 10 %, \$3.5 billion would be generated for the local economy, increasing opportunities for entrepreneurial jobs, skilled employment, and healthy foods. At the same time, there is a renewed interest in local foods to foster healthier North Carolinians and protect and preserve the rural landscape (Curtis et al. 2010).

There is a tremendous untapped opportunity for selling locally grown produce to indirect markets such as stores, restaurants, institutions, and distributors, particularly for small growers that cannot market their produce directly to consumers. Developing a marketing network geared toward these small and micro-farmers simultaneously builds the resilience of local economies through job creation, the resilience of the food system through a diversified, decentralized network of small suppliers, and resilience in production through cultivation of diversified crops.

Many of the jobs that have been created since the end of the recession have been low-wage service jobs. Rural areas of North Carolina continue to lose jobs, while metropolitan areas slowly begin adding new jobs (Forter et al. 2013). This slow

economic recovery is a reflection of a lack of resilience in the local economy—largely in response to changes in the manufacturing foundation of the region. Fostering locally embedded sustainable, high-yield/low-input agriculture and markets for product sale has the potential to replace the former manufacturing economic foundation.

Potential for distribution, sale and access to locally produced foods in the North Carolina Piedmont region

To assist local governments in fostering sustainable neighborhoods through food, a model was designed to describe a decentralized, produce aggregation network serving small- and micro-producers within the North Carolina Piedmont (Piedmont Together 2013; Walker 2014). Questions of economic and food system resilience were addressed by asking:

What opportunities exist to build the supply and demand for local produce while engaging and involving rural and urban, low-resource, diverse communities in ways that generate individual and community wealth and security? More specifically, what sectors are not currently engaged in local food system efforts that hold potential for growing their businesses while contributing to a more robust local food system? (Walker 2014).

The economy of the Piedmont region of North Carolina during the latter half of the 20th century—dependent largely on low-skilled manufacturing jobs in textiles, furniture, and tobacco in urban areas and tobacco production in rural areas—is a prime example of low resilience, as attested by the lingering effects of the recent economic downturn. Similarly, while the prevalence and growth of farmers markets across the Piedmont is certainly a welcomed addition, a food system dependent on a small number of relatively high-priced, geographically distant markets with limited hours lacks the resilience possible in a food system that includes markets characterized by a high diversity of product, price, location, and methods of sale.

The goal of the model designed to address the participation gaps in the local food system described above was to enhance resilient economic development through creative and sustainable diversification of employment opportunities and market types within the local foodshed through opportunities for aggregation, storage, and sale of local food products, exploiting the growing diversity of locally grown agricultural products.

Figure 1 shows the model developed. Dashed boxes, focusing on micro-, small-, and medium-scale aggregators, are assets that could provide opportunities for sale and distribution of local foods from small- and micro-scale producers that currently lack many opportunities for indirect sales of their products. These small-scale aggregators would fill a niche that links a diverse set of producers (part- and full-time, rural and urban) and diverse agricultural products to retail outlets that cater to populations that currently lack access to local food,

such as small rural grocers, urban convenience stores, locally owned mid-priced restaurants, and city- and county-managed institutions. Diversifying crops also provides opportunities for consumer access to more diverse produce and other foods, such as culturally important or desired foods. This model demonstrates one method by which resilience is increased through supplementing and integrating with the existing, larger-scale food system, not creating a parallel, stand-alone “local” system.

Resilience, defined earlier as the capacity for a system to absorb disturbance and to reorganize, while retaining system function, structure, and self-organizing processes, can best be achieved within the food system by more food produced, distributed, and consumed within local geographies, while keeping the larger—even national—structures that fill gaps which cannot be filled locally or where those structures inform and support local efforts.

Another important concept model is illustrated in Fig. 2, where the inner ring of the diagram shows a direct-to-consumer relationship within a typical local food system. While this smaller model is more highly favored by local food system activists who place a priority on “knowing one’s farmer,” it can exclude opportunities for generating community wealth, resilience, and new jobs through the multiplier effect: increasing the number of times a dollar cycles through a community increases the economic impact of that dollar on the local economy (Morgan 2006). A study by the Iowa State University concluded that buying local food has a multiplier effect of 1.4–2.6 throughout the wider local economy, depending on the rural or urban context and commodities and scale of the community economy (Swenson 2007). Additionally, current research suggests that adding one skilled job in the tradable sector generates 2.5 jobs in local goods and services, with high potential for the non-tradable sector (Moretti 2010). The larger circle in Fig. 2 illustrates the inclusion of these “value-added” industries, including aggregators, institutions and wide variety of retail outlets.

The larger circle also illustrates multiple points of entry for community members into a food production/aggregation/processing/distribution network. Programs such as farm incubators can provide training and technical assistance in sustainable production techniques (e.g., biointensive, agroecology), access to on-farm resources and infrastructure, initial entry into post-harvest processing/marketing, and land access opportunities to facilitate the start of new businesses. Additionally, underutilized facilities such as convenience stores, restaurants, grocery stores, and local institutions can provide the capacity for storage, post-harvest processing, and/or distribution that can serve as points of entry for people interested in starting non-farm food system enterprises. Retail outlets such as restaurants, small grocers, institutions, and innovative outlets, for example mobile or pop-up markets, can widen the distribution of the local food network increasing

Fig. 1 Conceptual food aggregation model showing the flow of produce from farms of different scales to a diversity of market types, mediated through aggregation channels (Walker 2014)

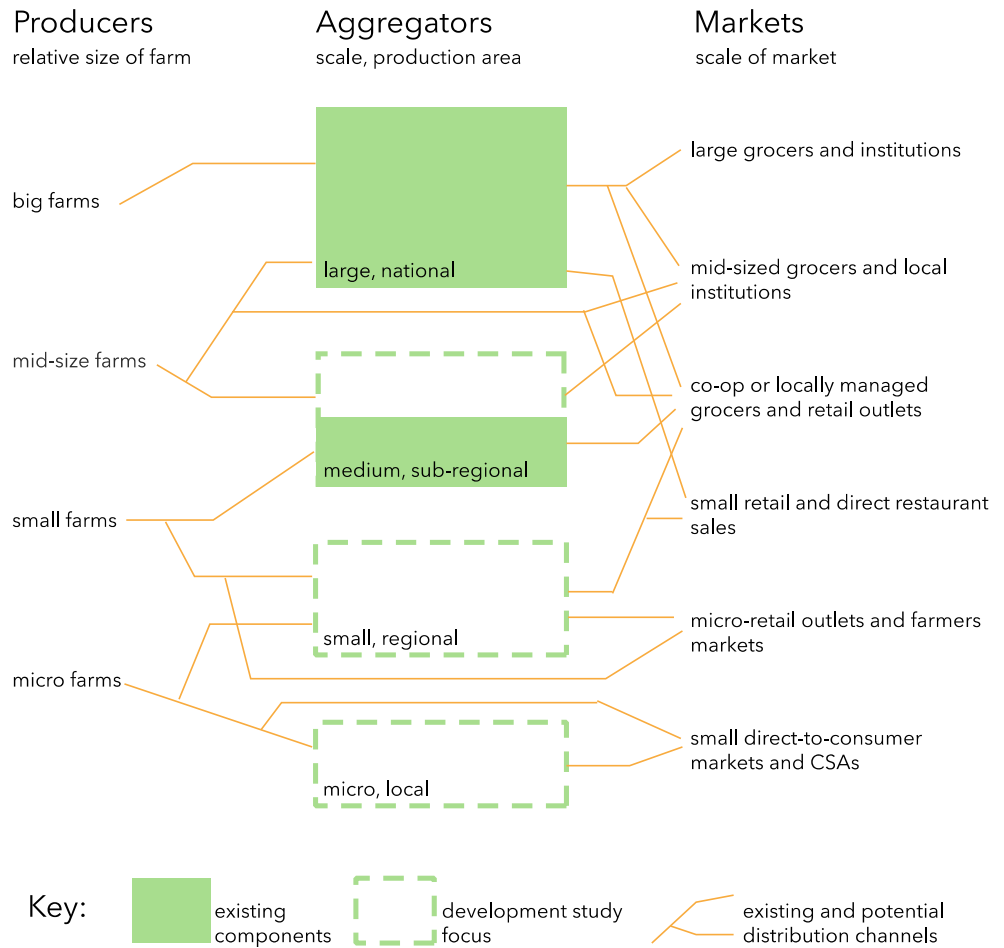
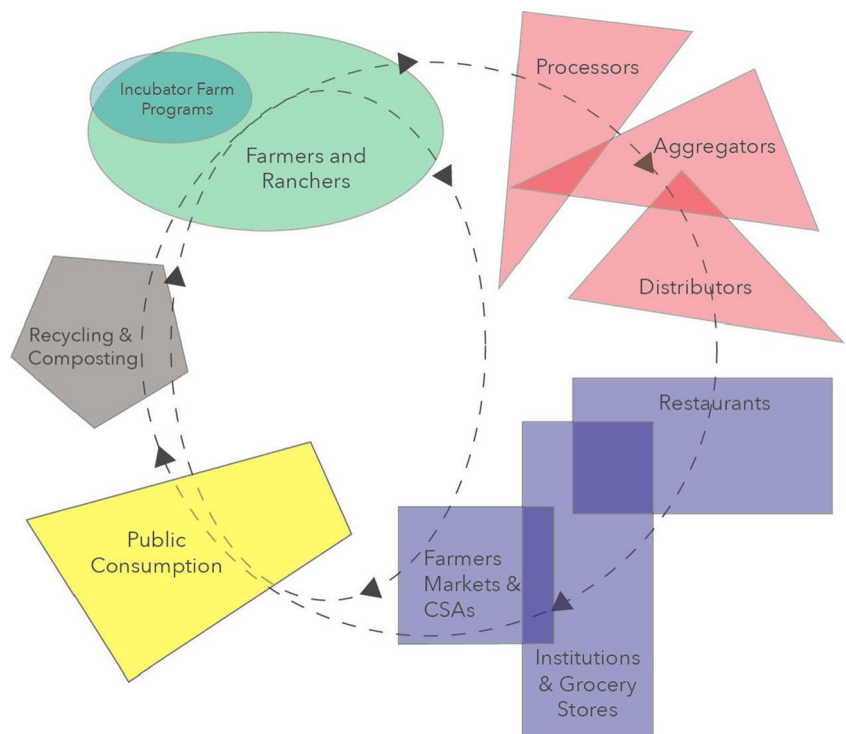


Fig. 2 Diagrammatic model of a food network, showing direct markets (*inner circle*) and the inclusion of intermediaries (*larger circle*) that produce economic multiplier effects (Walker 2014)



access for community members who would not normally be a part of a regional foodshed based only around direct farm-to-consumer marketing.

Currently, there are a number of projects, programs, and initiatives geared toward assisting mid-scale farmers who wish to enter mainstream markets. For example, started in 1997, the North Carolina Farm to School Program now facilitates sale of locally grown food to 87 of the 100 counties in North Carolina. During the 2013–2014 school year, \$1,350,263 was spent purchasing fruits and vegetables grown in North Carolina, which were then served in schools (North Carolina Department of Agriculture and Consumer Services 2014).

Both approaches are necessary to build a resilient local food system that can absorb disturbances such as natural disasters and disruptions to the national economy and transportation network. The models illustrated in Figs. 1 and 2 highlight the opportunities for new, small-scale, locally-based markets that can be the portal for sale of products by locally-connected producers, thus increasing the resilience of the food system through dynamic, adaptive, and responsive enterprises.

Challenges

To achieve this increase in locally sourced food through decentralized, networked distribution channels, three main issues must be addressed.

- 1) Many of the resources for the promotion of local foods development over the past decade have gone to supporting mid- and larger-scale farms within North Carolina. Large foundations and universities have focused on helping farmers who were affected by the tobacco buyout program transition to other viable crops, as well as the renewed public health focus on obesity, diabetes, and stroke prevention. This led to much public support for getting fresh, local foods into a variety of markets and food access programs. Working with larger farmers and distributors has made a difference in the prevalence of local foods available to consumers. However, small-scale farmers are often not able to sell to these markets.

For example, during the 2012–2013 school year, the North Carolina Farm to School Program purchased strawberries from only 7 farms and sweet potatoes from 11 farms. For comparison, there are 4155 North Carolina farms of 1–9 acres identified in the US Department of Agriculture Agricultural Census, who are also potential suppliers for this program (North Carolina Department of Agriculture and Consumer Services 2014; US Department of Agriculture 2014). In order to engender greater resilience of the local food system, more attention

needs to be paid to the contribution potential for small- and micro-scale farms.

- 2) Nationally, the local food movement has often been hegemonic in its lack of inclusion of minority participants—be they underrepresented racial, ethnic, class, or genders (Hinrichs 2002; Jarosz 2008). Greater attention paid to the barriers for participation by individuals, businesses, and communities that are not currently part of the local food movement will help in creating greater equity of food access, economic opportunity, and environmental health (Holley 2012). It will also expand the range of products available for production, processing, and purchase, increasing both social and economic resilience within the local network.

In the same way that a diversity of scale and market type will strengthen the ecosystem of the local food system in the Piedmont region, greater involvement from a diversity of stakeholders throughout the system will engender more dynamism and resilience (Page 2007; Holley 2012). Expanding and diversifying the community of growers and non-farm entrepreneurs will also expand markets and market access to parts of the community now underserved by a centralized food marketing network.

- 3) For many small farmers, resources and equipment that would facilitate sale to a network are not available. For example, the cost of an 8 × 10' cold storage unit is typically \$4000–\$10,000. For many farmers who have substantial capital, off-farm income, or access to credit, this is attainable. However, need for capital is a barrier for most low-resource farmers.

Guidelines for a decentralized storage and distribution network

The local food models outlined above for central North Carolina's small and mid-sized farmers and aggregators can be described in a set of five “design guidelines” that increase economic, social, and agricultural resilience. These guidelines are intended as a beginning resource for people interested in starting or adding to some aspect of the decentralized aggregation and cold storage local food network. They are suggestions that can be utilized by decision makers, designers, and planners that may be working on other community-wide issues such as transportation, housing, and economic development. Having design guidelines that summarize a model of diversification and resilience based on food system localization allows for the inclusion of ideas generated through academic research into practical, applied community practice.

Guideline #1: Promote networks and nodes Intent: *Develop a regional food system that utilizes complexity (a system of*

networks and nodes) as a mechanism for achieving greater economic and food system resiliency.

- A. Look for opportunities to situate aggregation and storage facilities throughout the region and close to production farms, while encouraging strong interconnectedness throughout.
- B. Cluster small aggregation and storage facilities near one another, forming “nodes” of the local food supply chain. Fifty miles has been defined as a maximum distance between aggregation facilities in rural North Carolina (Bruno and Hossfeld 2009). Facilities may be closer in the more urban Piedmont.
- C. Identify and strengthen shared values, goals, and visions among businesses and initiatives participating in all aspects of the local food supply chain. Consider values-based supply chains (value chains) in lieu of traditional supply chains. In value chains, chain partners share values and vision, maintain open communication, and share equitable profits across the chain.

Guideline #2: Engender equity and inclusivity Intent: *Build on the strengths of the Piedmont Triad region by integrating cross-barrier collaborations into the aggregation or cold storage business initiative.*

- A. Understand the political geography of your community. While doing business in a new area may present challenges, new business opportunities, collaborators, and markets also await.
- B. Build new lines of community rapport across racial, economic, class, and language boundaries.
- C. Work to promote access to financing and entrepreneurial assistance for diverse communities that are specific to current trends in food system development.

Guideline #3: Plan for appropriate transportation options Intent: *Ensure that the cold storage chain of all produce is maintained from farm to fork and that handling is appropriately documented. Each segment of the supply chain should work in tandem with other segments.*

- A. Ensure that there is access to a refrigerated truck or trailer to maintain the cold chain.
- B. Know the acceptable upper and lower temperature and humidity limits of the produce being aggregated.
- C. Manage traceability of products. Keep all appropriate records regarding the place of origin, place of sale, and storage notes for all produce that moves through the aggregation facility.

Guideline #4: Design an effective management plan Intent: *Design a management structure and plan that addresses the goals and limitations of your aggregation or cold storage business, while adhering to all regulatory requirements.*

- A. Choose a management structure that fits with your business. A simple cold storage unit leased to several farmers who are marketing their own produce to aggregators will still require facility management, rent collection, and marketing to new farmers.
- B. Ensure that your facility is compliant with all regulatory requirements, including appropriate recordkeeping. Track and document temperature and humidity through the duration of the entire supply chain.
- C. Develop procedures that allow access to storage space by clients when needed and ensure that everyone who enters keeps appropriate logs for food safety requirements.

Guideline #5: Build appropriately-sized cold storage facilities Intent: *Invest in infrastructure wisely. Cold storage units can be re-configured, and their temperature and humidity changed with relative ease if planned for up front. However, there is an economy of scale, even when working exclusively with small-scale farmers and buyers. Develop a business plan that helps to determine what and when your enterprise should build.*

- A. Estimate how much cold storage space you need based on the amount of produce your suppliers will need to store.
- B. Approximate energy costs ahead of time and investigate alternative energy as a way to lower the utility bill.
- C. Know what the optimal temperature and humidity settings are for each produce type you will store and aggregate.
- D. Determine what storage system you will use within the cold storage units based on the farmers and buyers you are working with. Some smaller growers who are storing their own produce to sell at a local farmers’ market may prefer industrial shelves where they can store produce boxes, while larger growers may prefer pallets and use pallet jacks to move their product around. Also, there is a need to consider the storage of certified organic and GAP-certified produce, which need to remain segregated from non-certified foods in order to maintain their certification.

Food production and access through a South Carolina food hub

The distributed network of aggregation and distribution centers proposed for the Piedmont of North Carolina provides an

integrated, regional model, reducing transport needs for farmers and expanding distribution, sale, and access. A South Carolina food hub has been successful in making local foods more available, providing an aggregation/distribution/service network to benefit farmers and consumers. GrowFood Carolina is presented below as a case study of a food hub that is helping the Charleston food system move toward a fledgling level of resilience. GrowFood Carolina provides a model for one of the nodes in Fig. 2—an aggregation/distribution hub that connects small-scale growers to consumers in the same region. It also has the potential to serve as a central hub networked to smaller aggregation and value-added processing centers throughout the region, like the spokes of a wheel.

Charleston, South Carolina is the center of one of the Southeast's real estate development booms, aided by an influx of retirees moving to the area due to its climate and the availability of still-relatively affordable land. Charleston County has grown from 350,000 in 2010 to almost 373,000 in 2013, a 6.5 % increase (US Census 2014). A corollary to the above growth and international recognition for Charleston's reputation is the recent development of a vibrant, local food culture. Green Grocer Farms on Wadmalaw Island, located outside of Charleston is representative of this growing local food culture. In the 1990s, the farm grew a variety of row crops under regional organic certification, which were sold in Savannah and Atlanta. Now, 15 years later, pastured eggs and pastured raw milk are produced, and the farm is unable to keep up with local demand for their products.

The growth in demand for local foods is also seen at the Charleston Farmers Market. Ten years ago there were approximately five farmers; now there are over twenty-six farms selling a variety of local and regional products, including meat, eggs, milk and cheese, vegetables, flowers, shrimp, rice and fruit. One other area of growth is in the local restaurant industry, where almost every local restaurant advertises that they support local farmers and purchase local food, with one nationally recognized restaurant, Husk, advertising a strictly regional menu.

GrowFood Carolina—a regional food hub

GrowFood Carolina is a working example of how a food hub contributes to resilience in the Lowcountry of South Carolina. The US Department of Agriculture defines a food hub as “a centrally located facility with a business management structure facilitating the aggregation, storage, processing, distribution, and/or marketing of locally/regionally produced food products” (US Department of Agriculture 2010). Food hubs have operational services which can range from aggregation to distribution and sale, including branding, promotion, packaging, and product storage. They can also assist with producer services, ranging from transportation, training, business guidance, value-added product development, and providing

liability insurance, to an often key service, linking buyers with producers. Food hubs can also help with the promotion of community/social missions, such as distribution of products to food deserts, raising awareness about benefits of supporting local agricultural businesses, providing opportunities to community youth, offering composting and other forms of regionally-appropriate farming/agricultural workshops.

GrowFood Carolina is a subsidiary of South Carolina's leading environmental advocacy group, Coastal League (CCL), started in 1989 with the mission to “protect the natural environment of the South Carolina coastal plain and to enhance the quality of life in our communities by working with individuals, businesses, and government to ensure balanced solutions” (Coastal Conservation League 2014). To realize this mission, in 2009, CCL started two “in-house” policy and advocacy groups to help protect the coastal corridor of South Carolina. One group focuses on climate change and energy, while the other group focuses on sustainable agriculture.

The CCL Sustainable Agriculture committee helps CCL's overall strategy of land conservation: if farming is not economically viable, then small and mid-sized farmers will be squeezed out of the market with subsequent changes in land use. Thus, CCL actively supports local, sustainable agriculture. To support their mission, GrowFood was created to provide infrastructural help to regional small- and mid-sized farmers.

In 2010, a 6500-ft² warehouse in downtown Charleston was donated to CCL. After renovating it and hiring a general manager, GrowFood officially opened for business in 2011. The warehouse contains 1400ft² of refrigerated space. Although not climate controlled, the building meets Leadership in Energy and Environmental Design (LEED) standards. GrowFood also owns a 15-ft refrigerated truck purchased with funds from a US Department of Agriculture grant and has an urban garden demonstration plot on site where they host various workshops and school groups. The warehouse is located directly off interstate I-26 leading inland to Columbia, SC, and is close to Hwy 17, a North/South artery. This location is strategic, allowing GrowFood to meet its mission as a food hub, consolidating production and distribution within a 120-mile radius. This radius allows GrowFood to work with farmers growing produce from Georgia to North Carolina, and CCL has plans to open a second hub in Greenville, South Carolina that will service the upstate, mountain region of South Carolina.

Farms within the 120-mile radius contact the GrowFood General Manager, who visits the farm for “full transparency.” At that time, GrowFood helps farmers generate a 52-week growing plan so each farmer is better positioned to meet demand and generate a supply of produce that is marketable, thus building the resilience of the individual farmer, and, by extension, the resilience of the local food system at large.

Farmers work on consignment, dropping off produce once or twice a week, at which point they receive a purchase order, but no payment. GrowFood then is contacted by local

restaurants and retail stores, and GrowFood either delivers the produce, or retail customers come to purchase it from the warehouse. After a sale, 80 % of the purchase price returns to the grower, and 20 % remains with GrowFood to help cover operating costs.

GrowFood does all sales, marketing, and distribution via a two-person marketing team, and they work with over 300 local businesses, distributing 5 days per week. This requires five full-time staff and two part-time drivers. In 2011, they had five growers and 15 customers, and as of 2013, they have 35 growers with 85 regular restaurant and 10 retail customers. Currently, demand far outstrips supply, demonstrating demand for additional local foods and food hub services in the South Carolina foodshed. With 2135 farms from 1 to 9 acres in size in South Carolina, clearly, there is additional production and distribution capacity (US Department of Agriculture 2014).

The goal of the CCL staff is to expand both GrowFood as well as the local farming community, helping them to diversify, increase production and transition to organic production. Therefore, besides retail distribution, GrowFood is an advocate for small-scale, sustainable farming. South Carolina currently has 15 certified organic growers, compared to over 700 in North Carolina. To expand the number of SC organic growers, CCL does outreach and education about the benefits of sustainable agriculture, focusing especially on the next generation of farmers.

The average age of farmers in South Carolina is 63. There are currently not enough young farmers to supply current demand, let alone create new farms that can help meet growing regional food needs. But this also presents an entrepreneurial opportunity for increasing the resilience of the regional food system through creation of new, small, sustainable farms if land, training, and resources for start-up business are made available. Dirt Works Incubator Farm on Johns Island outside of Charleston is working to support development of new farmers starting their new farm businesses in the area.

GrowFood as a food hub is helping the community in three important areas.

- “The environment.” Use of sustainable production techniques that improves the soil with each cropping cycle and use of the food near the production farms, reducing transportation impacts
- “Diversify local agriculture.” Smaller farms have the adaptive capacity for increased diversity of crops in production both on-farm and between farms, also increasing nutritional and preference opportunities for consumers.
- “Rural economic development.” As the manager of GrowFood stated, “Cash flow is the most important thing for a grower.” This cash flow allows farmers to be economically solvent, allowing them to continue farming. Median income in South Carolina is \$44,623, well below the national average, with 18 % living in poverty.

Despite the ready support of local restaurants, it is recognized the client base needs to expand, so further goals are to sell to local schools, hospitals, and retail supermarkets, and to advocate for a year-round farmers’ market. Lastly, their larger goal is to have 80 % of Charleston’s food come from within the 120-mile radius of the food hub by 2030. If successful, Charleston and the Lowcountry will demonstrate a powerful move toward food resilience as a disturbance response.

Thus, CCL’s goal is to develop an aggregated food hub network in the state, as is proposed for the North Carolina Piedmont in the previous section, while working on education and training, advocating for policy shifts at the state level, and creating food network market resilience. Food hubs can potentially add redundancy and resilience at regional scales and across industries (production, distribution, consumption) and thus act as catalysts fostering reorganization of regional food networks.

As anyone who has farmed knows, if a farm cannot make money, then there will be no farm. Food hubs can become key nodes in food networks, and because they interact with farmers and retailers on a daily basis, they can serve as a platform to quickly disseminate information, creating synergies between and among the diverse members of a food system. Rapid information transfer throughout the food network strengthens adaptive capacity for growers, processors, and distributors, allowing rapid response to changes in market and/or environmental conditions.

However, a note of caution: food hubs may not be appropriate in all places, and local production may not fill all food needs. Even GrowFood is years away, at best, from helping create a critical mass of local farms that can provide even a small percentage of the Lowcountry’s daily food needs. The food hub model in South Carolina and the proposed model for North Carolina may also be appropriate for other regions, extending the capacity of the regional food networks with strengthened resilience.

Conclusion

It is an open question as to whether our global food system contains the capacity to respond to a variety of disturbances, which may threaten the integrity of system function and structure and the ability to provide needed food to all people. By definition, if such structure and function were to collapse and be unable to reorganize, such a food system lacks resilience, with potentially severe human consequences. However, adaptive capacity and adaptive management acknowledge that a system being managed will always change, so humans can respond by adjusting the system in response to disturbance and changing conditions (Gunderson 2000, 2001, 2002). In the case of agriculture and food security, resilience can be considered from the perspective of food availability with a return to a predictable, dependable, safe supply following

disturbance. This issue of the *Journal of Environmental Studies and Science* grapples with diverse perspectives of this challenge (Marten and Atalan-Helicke 2015).

While appearing to make agricultural production more consistent and predictable, genetic uniformity also has the potential to increase risk from pests, pathogens, and other disturbances, as highlighted earlier in this paper. In contrast, high biological diversity has the capacity to decrease risk with genetic diversity within a single crop and through distribution of risk between a variety of products being grown for harvest and sale. These insights should help us think more clearly about what are long-term goals for a truly resilient food system.

Small-scale, locally-managed farm operations using agroecological techniques such as biointensive agriculture have the adaptive capacity for increasing biological and ecological diversity both on and between farms, increasing resilience through the ability to rapidly respond to changing environmental and market conditions. Highly managed, low acreage production systems such as the biointensive technique have shown greater yields per unit area than conventional production systems reliant on larger acreage. These highly managed systems also result in more efficient water use, reduced pest/pathogen pressures, and protection of adjacent environments. Interspersing small farms with large farms and returning some lands to a non-farmed condition to provide localized ecosystem services has the potential to engender social, economic, and environmental resilience through regionally-enhanced, responsive, and more highly-integrated food networks.

Development of small, diverse farming operations can help communities respond to chronic economic stress by providing supplemental income for some growers and opportunities to build larger, full-time farm businesses for others. High-yield, low acreage techniques can also make farming accessible to a diverse community of people who had not been involved with agriculture, such as urban residents, minorities, and women. However, one barrier to small farmers is often inconvenient access to markets for sale of their products. To have a resilient food system, you have to make it economically viable to farm. Therefore, it is crucial to link the shift in food production systems with the shift in food distribution networks.

There is a growing emphasis for the need for new, locally based markets that can be the portal for sale of products by small-scale, locally connected producers. Indeed, several regional food hubs and networks have emerged in the USA that aim to close the gap between producers and consumers. Regional food network and hub models can increase opportunities for direct consumer purchase, or they can serve as aggregation centers for food to be passed into a centralized distribution network, connecting with large volume sellers such as grocery stores, processing facilities, and wholesale distributors. A food system that is predicated upon supporting and cultivating farmers of all scales, who utilize various

sustainable production methods for a diversity of crops, and have a variety of market outlets will inevitably be stronger, more resilient, and more adaptable to change than a system that only responds to one scale or type of farmer or one type of market.

Using biological and agricultural diversity to expand locally based, sustainable farming systems, foster new farmers and food entrepreneurs, and build distributed aggregation, processing and marketing networks that focus on triple bottom line benefits—environmental, social, and economic—have the potential to strengthen our food security and our communities, providing resilience to both acute and long-term stress.

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