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Resilience and the industrial food system: analyzing the impacts of agricultural industrialization on food system vulnerability

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Analyzing the impacts of agricultural industrialization on food system vulnerability

Abstract

The purpose of this paper is to explore how socio-economic and technological shifts in Canadian and American food production, processing and distribution have impacted resilience in the food system. First, we use the social ecological systems literature to define food system resilience as a function of that system's ability to absorb external shocks while maintaining core functions, such as food production and distribution. We then use the literature to argue that we can infer food system resilience by exploring three key dimensions: (1) the diversity of the food system's components, (2) the degree to which the components are connected, and (3) the degree of decision-making autonomy within the food system. Next, we discuss the impacts of industrialization on these three factors within Canada and the US. Specifically, we show how processes of corporate concentration, farm-scale intensification, mechanization, and the 'cost-price squeeze' have led to a decrease in ecological and economic diversity, a high degree of spatial and organizational connectivity, and a diminished decision-making capacity for individual farmers. While this analysis is qualitative and heuristic, the evidence reviewed here leads us to postulate that our food system is becoming less resilient to external shocks such as climate change. We conclude by discussing four possible strategies to restore resilience, and suggest a more transformational shift in food system politics and practice. Specifically, we argue that publicly led multifunctional policies may support more diversified production while programs to promote food system localization can increase farmer autonomy. However, these shifts will not be possible without social-structural corrections of current power imbalances in the food system. This policy discussion reinforces the value of the social ecological framework, and specifically its capacity to produce an analysis that interweaves ecology, economy, and power.

Key Words
Climate change; resilience; adaptive capacity; agriculture; farming; industrial food system

Introduction

The most recent Intergovernmental Panel on Climate Change report projects that between 2080 and 2100 we will likely experience, or exceed, a two-degree Celsius global warming, leading to more common and severe extreme weather events, shorter and warmer winters, longer summers, as well as greater variations in precipitation (Collins et al. 2013). These shifts will likely lead to changes in agricultural yields depending on region, latitude, and pest and disease dynamics (IPCC 2014). However, much remains uncertain, as climate change is not exclusively a biophysical phenomenon. Rather, it is influenced by the social, political, and economic systems with which climate change interacts. For instance, when we consider food systems, it is vital to note that social and political factors significantly impact the capacity of those within the system to adapt to climatic changes. Understanding the ways in which industrialization has shaped contemporary agriculture, therefore, is vital if we hope to anticipate whether our food systems have the capacity to withstand the sorts of shocks and stresses already observed and predicted by climate models.

To explore this issue, the purpose of this paper is to provide insights into the following question: how have recent social and political-economic shifts in the food system influenced the system's capacity to adapt to stocks and stresses? To answer this question, our paper proceeds in the following way. We begin by exploring the relevant literature on 'social ecological systems' insofar as this body of work defines concepts of vulnerability, resilience, sensitivity, and adaptive capacity (Gunderson and Holling 2002; Folke 2006; Brown 2014). Next, and using the conceptual tools from the social ecological systems literature, we explore ways that industrialization in Canadian and American food and farming are influencing the system's resilience to shocks and stresses. Finally, we reflect briefly on possible policies that can be enacted to enhance resilience in the future.

We would like to note that this analysis of food system resilience is not intended to be exhaustive. Rather, we have striven to provide a preliminary and heuristic appraisal of these issues to demonstrate how social-economic and political factors interact with environmental and climatic dimensions. In this way, one of our goals is to build on the strong interdisciplinary tradition of creating qualitative frameworks through which to explore food systems (see: Watts and Bohle 1993; Ericksen 2008; Hinrichs 2014) but this paper makes a distinct contribution to this field by applying evidence documenting recent changes in the nature of Canada and the USA's food system to these conceptual tools.

Framework and theory

We begin with a review of the relevant social ecological systems literature, and specifically, its definitions of resilience, vulnerability and adaptive capacity. It is crucial to note that resilience has been defined and applied quite differently across disciplines. One way to define resilience through the social ecological systems body of work is, "the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change." (Engle et al. 2013). As applied to the food system, we can define 'food system resilience' as the ability of a food system (which itself is made up of actors who produce, process, transport and distribute food) to address stresses and disturbances while providing stable levels of consistent nutrition to the public. Notably, the simplicity of this definition is not intended to exclude attention to power, politics and normative goals of resilience—effectively explored through the transformation in resilience and adaptation literature for instance (Pelling 2011; O'Brien 2012; Brown 2014)—but rather to apply it as a clear measure, thus allowing such exploration to occur through multiple lenses during analysis. An approach we hope to, at least partially, achieve in this paper.

The social ecological systems literature is also useful in that it provides conceptual and heuristic tools to evaluate the extent to which the resilience of systems may be changing over time. In particular, this body of work has proposed the *adaptive cycle* as a way of observing whether social ecological systems are reaching tipping points, which are defined as conditions beyond which resilience may be quickly eroded (e.g. see: Gunderson and Holling 2002). The adaptive cycle is relevant in that it emerged from ecological studies to explain why some ecosystems seem stable for long periods of time but then collapse in a sudden reorganization. For instance, the boreal forest of northern Canada grows steadily for many decades until it reaches a threshold, at which point chance events, such as lightning strikes, cause massive fires. Of note, the adaptive cycle has subsequently been applied to various social-ecological systems (Adger et al. 2005; Adger and Brown 2009; Cote and Nightingale 2011). Authors who have used the adaptive cycle as an analytic framework posit that the generic characteristics of systems on the verge of collapse (i.e. low resilience) include: *low species diversity* and *high spatial connectivity* amongst individuals (Gunderson and Holling 2002). For this analysis, these two particular components—diversity and connectivity, along with a third—decision-making autonomy, will be adopted as they offer a clear yet comprehensive lens for analyzing relationships in a social-ecological system. Since these characteristics and their utility to the analysis of resilience have been defined many times by scholars (Peterson et al. 1998; Gunderson 2000; Berkes et al. 2003), below we provide our own understanding of these terms and explain how these concepts will be used in this paper.

Diversity

Diversity is understood here as a level of species richness that is functionally effective for the given system (Peterson et al. 1998). Analyzing functional diversity requires more than a species level assessment. For instance, in farming systems a three-crop rotation that has a grain (such as maize), a forage (such as clover), and a legume (such as alfalfa) would have more "functional diversity" than a four-crop rotation made up of cauliflower, cabbage, cress, and broccoli, as these four crops are all part of the brassica family and hence are vulnerable to similar pests. Maintaining functional diversity is particularly important because diversified crop systems have been shown to better withstand pest outbreaks, price instabilities (as the farmer has different kinds of crops to sell and eat), and weather perturbations than more specialized systems (Abson et al. 2013). Hence, the literature on "functional diversity" concludes that if, over time, there is a reduction in crop diversity, then that farming system will likely become more vulnerable to ecological, political and economic disturbances (Jackson 2002).

Connectivity

A system that is tightly connected across the landscape allows "disturbances to pass quickly from one individual to the next and from one landscape scale to the next." (Fraser et al. 2005). Connectivity is important here because it forces us to consider how different scales may interact, since in tightly connected systems, processes that occur within one scale (such as the agroecosystem or field scale) may impact other scales (such as the watershed). For instance, the landscape of the Irish Potato Famine[1] was one of continuous potatoes, with small tightly packed fields and minimal land left uncultivated (Fraser, 2003). If, however, these fields were separated by margins (buffer strips, wood lots, or windbreaks etc.) then the blight that infected potato crops would not have spread as far or as fast. A more recent illustration of the possible impacts of high connectivity can be seen in the ongoing Porcine Epidemic Diarrhea virus (PEDv) outbreak that has led to the death of roughly 10 percent of the U.S. pig population (Davis & Waters, 2014). Essentially, PEDv is contagious and has spread across 30 states in under a year, despite significant efforts to ensure sanitation and cleanliness along the supply chain. Although PEDv is extremely infectious (little more than a tablespoon of PEDv infected manure is enough to "infect the entire U.S. hog herd" (Davis & Waters, 2014)), it is important to note that cleaning and disinfecting production and distribution sites has done little to mitigate the fact that U.S. hog production is highly integrated and therefore vulnerable (Becton 2014). In fact, it is the distributed network of thousands of independent growers across the country, and their physical separation, that is providing some measure of control at this time. The trend toward consolidation in the food system is clearly correlated to the trend toward spatial connectivity. Indeed, the rise in spatial connectivity is largely driven by economic forces, which will be explored in detail below. Thus, spatial connectivity must be understood in light of concentration and consolidation in the food system—defined here as economic connectivity.

Decision-making autonomy

The third component of resilience applied in this paper is "decision making autonomy." While not part of Gunderson and Holling's original conceptualization of resilience or the adaptive cycle, this concept has emerged as an important element of social-ecological systems research. Decision making autonomy is defined as the degree of control that producers have over production as well as their ability to observe and respond to feedback mechanisms (Folke 2006; Hammond et al. 2013). For example, a producer may be very keen to implement organic methods or become more ecologically adaptive. However, for a number of reasons, conditions may be such that they do not have the power or control over production to make those changes themselves.

Furthermore, decision-making autonomy is an important factor that determines the extent to which connectivity may exacerbate vulnerability. In particular, there are many situations where problems can quickly spread in tightly connected systems (such as PEDv). However, positive adaptations can also spread in connected systems (such as the adoption of innovative farming practices or better disease control measures). To a large extent, however, this depends on the ability of the individual farmer to change management practices. This, in turn, depends on decision-making autonomy (e.g. Fraser et al. 2005). Hence, the focus this paper places on decision-making autonomy builds on conclusions from the body of scholarship that defines adaptive systems as those with the ability to learn and change behavior (Adger 2006).

Interconnectedness of diversity, connectivity and decision making autonomy

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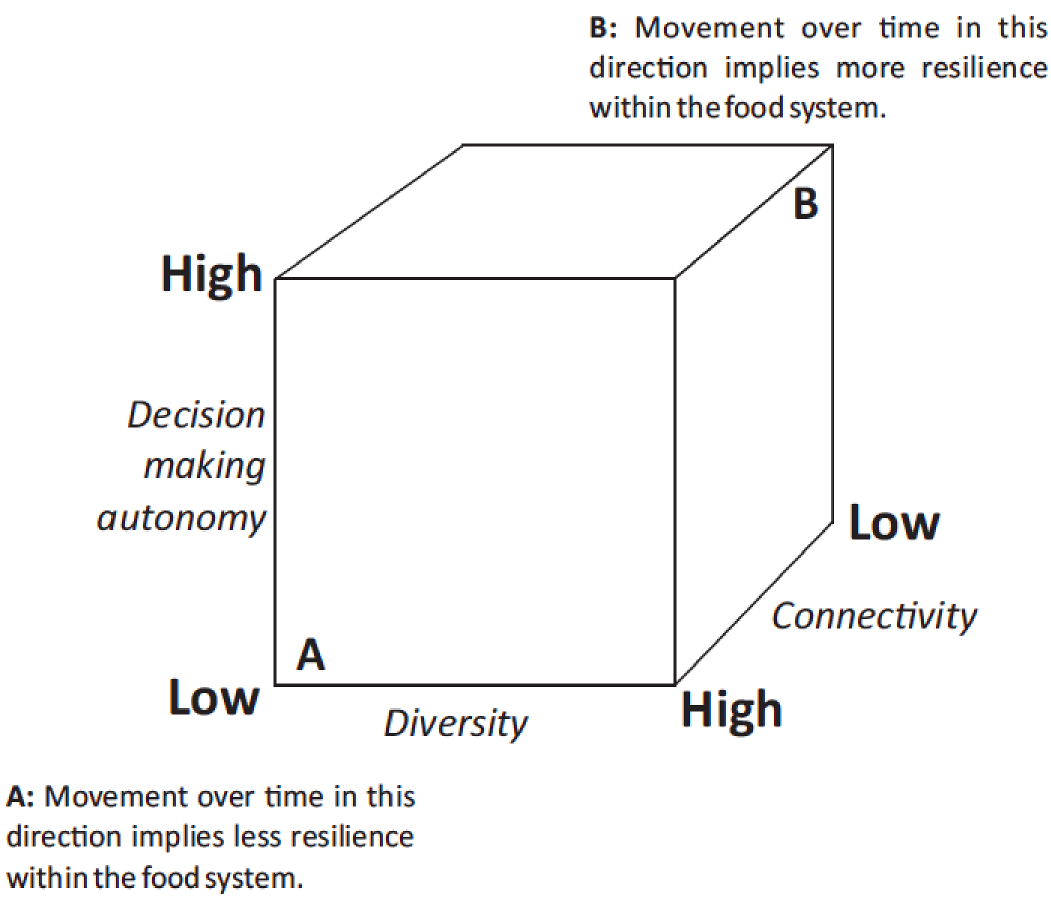
[1] Occurred between 1845 and 1850 and was caused by a potato blight that triggered a famine which killed or displaced 25% of the Irish population (Fraser 2003).

The three factors we have identified do not operate independently. Indeed, as diversity increases, and ecological or social niches fill-in, connectivity may also rise. Fraser (2007) addresses this point in a study on the factors that make livelihood systems vulnerable to famine, where he conceptualizes vulnerability as three interrelated factors that can be visualized as the axes of a cube (see figure 1; see also Fraser et al. 2011). Drawing on this, we propose that the three factors we have identified in this paper may heuristically be displayed as the X, Y, and Z coordinates of the "resilience space" where changes along any of the three axes may, albeit rarely, operate independently, or be affected by other factors. What is important in terms of resilience is the *overall direction of the trajectory a food system takes over time*. A food system moving toward the bottom, left, front corner of this space is one where decision-making autonomy is declining, diversity is decreasing, and connectivity is rising. We argue that such a food system is becoming more vulnerable to external perturbations and shocks than a food system that is moving toward the top, right, back corner.

Figure 1:



Impacts of agricultural industrialization on food system vulnerability and resilience

In this section, we will use the three components presented in section 1 to assess the ways in which socio-economic, policy and technological trends over the past 50 years have influenced the resilience of the North American farming sector.

Diversity

Evidence for changing diversity

Overall, a number of independent bodies of evidence suggest that functional diversity has declined on US and Canadian farms due to agricultural industrialization (Fragoso et al. 1997; Matson et al. 1997; Tilman et al. 2001; Tilman et al. 2002; Tscharntke et al. 2005). Given the rise of industrialization in Canadian and American agriculture (Vandermeer et al. 1998; Lin 2011), understanding the effects of declining diversity is especially pertinent. Both globally and within the U.S. and Canada, the trend toward homogeneity is clear, with an average global rise in crop homogeneity of 16.7% between 1961 and 2009[2] (Khoury et al. 2014). For example, in Illinois—which devotes 66 percent of total land to agriculture—maize and soybean crops rose from 45% of Illinois cropland in 1958, to 86% in 1997 (Liebman et al. 2001). Similarly, by 1991, "production of the same crop in the same field for at least three consecutive years was found on 86% of the land used for wheat in Oklahoma, 82% of the land used for cotton in Louisiana, 57% of the land used for soybean in Mississippi, and 55% of the land used for maize in Nebraska"(Liebman et al. 2001). In the U.S. generally, acreage of corn and soy crops continue to rise (Bretting et al. 2011). These trends, supported by analyses showing correlations between crop homogeneity and declining farm-scale biodiversity (Blackwell and Dolbeer 2001; Hooper et al. 2005; Potts et al. 2010; Mutoko et al. 2014), point to declining levels of on-farm diversity.

In addition to declining diversity of crop types, evidence also shows increasing adoption of hybrid varieties and an overall reduction of varieties grown within crops. Commercially available varieties of peas, for instance, fell from 408 in 1903 to 25 in 1983; over the same period, sweet corn varieties fell from 307 to 12, cabbage from 544 to 28, and beets from 288 to 17 (Tomanio 2014). In many ways, the process of industrialization has caused these declines. Specifically, the mechanization of harvesting has placed strict requirements on physical and genetic uniformity—mechanical tomato harvesting for instance requires highly uniform size, ripening pace, and a consistently thick fruit skin (Pritchard and Burch 2003). As a result, only a small number of varieties are able to be cultivated under mechanized production systems. So, despite the kind of "pseudo diversity" (by which we mean a vast range of consumer products) seen in grocery store aisles, a significant drop in the richness of varieties for single crops has occurred. In Nova Scotia, for example, the number of apple varieties planted in orchards has gone from over 2000 varieties in 1916 to just six major varieties, four of which take up 70 percent of the continental market (Winson 2013). The requirements of mechanization and economies of scale together have made the loss of varietal diversity especially prevalent in commodities produced via high density industrial farms and feedlots, or what Weis (2012) calls the *industrial grain-oilseed-livestock complex* that is made up of seven major commodities: maize, wheat, soybeans, canola, pork, poultry, and cattle.

[2] Measured by the mean change in similarity between each country and the global standard composition.

On the supply side, varieties are now selected for their conformity to mechanization, their shelf life, and their ability to survive long shipping processes, rather than on taste, health (both human health and health of the agricultural product itself), or ecological quality (Bonanno et al. 1994; Weis 2010). In this way, industrial systems of production have been built around goals of capital accumulation and efficiency maximization, thus making it more logical to manipulate ecological factors in order to suit capital-intensive infrastructure and practices, rather than to build our food production, processing and distribution infrastructure to benefit ecological diversity.

Causes of declining diversity

There are many factors that have led to declining diversity, and both Keynesian and neoliberal agricultural policy seem to have—in their own ways—led to a decline in diversity (McMichael 2013). In the case of Keynesian policy, current price support programs in Canada and the U.S have encouraged fewer commodities, larger scale production, and higher use of inputs. This is because subsidizing and protecting specific crops means it is more expensive and difficult for farmers to switch crops or diversify production (Berardi et al. 2011; Lin 2011). Traditional crop insurance programs have also reduced farmer flexibility and willingness to adapt to changing conditions and climate variability (Bryant et al. 2000). At the same time, the more recent process of liberalizing markets and embracing free-trade mechanisms has not diversified agricultural production either. In fact, free-trade mechanisms have led to further farm-scale specialization (e.g. see the following two papers for an exploration of this argument: Bradshaw 2004; Fraser 2006). This is because factors such as the promotion of agrochemical use, single crop machinery, crop-based financial loans, and pressure from both governments and agribusinesses to achieve economies of scale, all directly influenced the trend toward specialization, and remain intact under market liberalization (Bradshaw 2004).

Market concentration is also closely linked to the decline in on-farm diversity. The development of oligopolistic markets in the North American food system—wherein trade is now dominated by a small number of capital-rich transnational corporations (TNC's) and retailers who are able to exert significant structural and market power—has produced new forms of corporate conglomerates that control product chains from farm to shelf. For example, the top ten seed companies control approximately 50 percent of the U.S. market in seeds, five companies control 90 percent of global grain trade, 30 of the largest retailers control one-third of world grocery sales, and four companies produce more than 60 percent of agrochemicals (Clapp and Fuchs 2009; McMichael 2010; ETC Group 2013). Concurrently, private standards adopted collectively by this small set of powerful companies have strengthened transnational corporations' structural power while also pressuring participation from the smaller and/or weaker actors. For instance, when all major retailers enforce a production standard, many of the producers who sell to them have no choice but to accept the standard (whether or not the standard is applicable or beneficial to their method of production) (Clapp and Fuchs 2009). In addition, the negotiation of standards such as Global G.A.P or USDA Organic consistently include the companies with the capital and resources to attend and influence the negotiations, which also increases the ability of these corporations to control the subsequent practices implemented in the food system (Jaffee & Howard 2009). As such, agreed standards typically include technical requirements of production that suit these larger firms, but are unfeasible for smaller producers (Fulponi 2006). Such standards may also become weakened and focus on methods of production that are already being employed by the agri-business actors. As a result, many smaller actors may become unable to uphold the standard and be forced to exit the sector (Fulponi 2006). For example, Fridell illustrates this process with regards to fair trade standards:

> Starbucks is now among the largest fair trade roasters in North America—which promises to give TNCs immense influence on the future direction of the network. At the same time, TNCs may pose a significant threat to the viability of small-scale fair trade ATOS [*Alternative Trade Organizations*] (which generally sell 100% of their beans as fair trade), which lack the formers' financial and marketing resources. (Fridell 2004)

Implications of declining diversity for resilience

Farmers across North America are experiencing the effects of declining system diversity in a variety of ways. For large-scale producers practicing conventional agriculture, continuous cropping or simple crop rotations result in the loss of soil fertility (Bennett et al. 2012). A number of meta-analyses and field studies have shown that short rotations produce lower yields than longer, more complex rotations (Bullock 1992; Liebman et al. 2001; Lynch 2009; Davis et al. 2012; Challinor et al. 2014). It is also clear that short crop rotations require higher pesticide and herbicide applications (Pimentel et al. 2008). Therefore, the trends and forces outlined in the previous section are likely to be heightened as crop diversity declines. Indeed, increased commodity specialization has been shown to increase the producer's vulnerability to economic and ecological risks (Smithers and Johnson 2004).

For small and medium scale farmers, the effects of these trends on resilience have been more transformative in that declining market diversity via industrialization has forced many out of the farm industry entirely—evidenced through declining farm and farm operator numbers in both Canada and the U.S. (Osteen et al. 2012; National Farmers Union 2013). At the same time, declining market diversity has made it difficult for farmers to adopt ecologically beneficial practices. In the U.S. organic market for instance, establishing a label for organic produce actually "…made it easier for larger manufacturers and retailers to sell organic products, which in turn spurred the entry of larger organic farms and resulted in increasing concentration of the organic sector" (Cantor and Strochlic 2009). While the organic market has been growing at approximately 20 percent per year, smaller farmers have been negatively impacted as they are "…increasingly unable to gain access to the mainstream buyers that represent an increasingly large portion of the growing market." (Cantor and Strochlic 2009). In fact, in Canada, the trajectory for farming over the next 20 years, as projected by the federal government, is that most of the remaining small farmers will be operating what the government terms 'hobby farms'—which are not seen as economically contributing enterprises (Seccombe 2007). Finally, these processes illustrate the dynamic relationship between factors (i.e. market barriers for small farmers, increasing concentration, and the exit of small farmers from the industry) in that each condition can further reinforce and reproduce the other. The implications of marginalizing small and medium scale farmers and eroding their capacity to subsist are increasingly clear. Socio-economically, it means that even fewer members of society would have the ability to produce food. While, in itself, this isn't socially beneficial, having a low diversity of producers also allows food system disturbances to become amplified, both economically (consider food pricing controlled by few) and ecologically (contamination on a single farm can easily effect the entire country).

Connectivity

Evidence for rising connectivity

Evidence suggests that over the last fifty years, the North American food system has become increasingly spatially connected. The primary data for this are found in the statistics on farm numbers. In a matter of just 25 years, the number of farms in the U.S. fell by half – from approximately 6 million in 1940, to just over 3 million in 1965 (NASS 2009). In the U.S. tomato sector, for example, the number of growers dropped from roughly 4,000 to 597 between 1962 and 1973, while acreage and tonnage increased over the same period (Friedland et al. 1981). In Canada, farm numbers fell by 60 percent – from 732,832 farms in 1941, to 293,089 by 1986 (Winson 1993). This trend continues today, with a loss of 23,643 farms (10.3 percent) in Canada between 2006 and 2011, along with a 10 percent reduction in the number of farm operators over this same period (Statistics Canada 2011). Meanwhile, the total number of cultivated hectares of land has remained more or less constant. Hence, farm size has increased significantly, meaning that overall we have fewer, larger farms. This is what we refer to as greater spatial connectivity.

There has also been a trend toward consolidation and concentration in the food distribution and processing industry, a trend operating concurrently with increased trade in foodstuffs. These conditions are what we will refer to as economic connectivity. For instance, Canadian export values of agriculture and agri-food products increased from $10.9 billion in 1988 to $35.5 billion in 2010 (AAFC 2012). In the U.S. as well, total agricultural exports rose from $35 billion in 1988 to $108.7 billion in 2010 (Hanrahan et al. 2011). Trade in soybeans and soybean products, for example, rose from about 50 million metric tons to almost 200 million metric tons between 1990 and 2014. Additionally, many countries including Brazil, Russia, and Ukraine, along with areas of Africa and South America, are increasingly opening up their markets to trade and making substantial investments in agriculture. As a result of increasing trade, food commodities are gaining more and more “food-miles”; in the U.S., food has an average delivery distance of 1640 km and an average life-cycle supply chain distance of 6760 km (Weber and Matthews 2008). Finally, not only is food travelling farther distances as a result of international trade, but more food commodities are also travelling from certain concentrated production centers (such as California; the rising horticultural hub of the U.S.) throughout North America (Bonanno et al. 1994). For example, 73 percent of U.S. lettuce and 90 percent of U.S. tomatoes are now grown in California (Geisseler and Horwath 2013). In fact, California alone accounts for about 35 percent of global tomato production (Hartz et al. 2008). Overall, these trends demonstrate the nature and degree of connectivity occurring in the food system.

Causes of rising connectivity

The aforementioned increases in connectivity have been driven by many of the same processes of industrialization that were explained with respect to declining diversity. Building on this, the following factors are particularly notable: rising levels of capital intensiveness in farm production; market concentration in the processing and retail sectors; rising costs of inputs; and declining commodity prices up to 2008. Taken together, these elements have dramatically changed structures and methods of production and resulted in a more tightly connected food system in Canada and the U.S.

Specifically, in the 1950's, farm input and processing companies (bolstered mainly by U.S. capital) gained substantial power within the food system[3]. By 1962, the largest 50 processing firms in the U.S. controlled 70 percent of market sales (Winson 1993). Concurrently, North American farmers became increasingly dependent on inputs of all kinds (machines, fertilizers, and pesticides), and consequently, the corporations that sold them. Without a dramatic increase in the price at which farmers could sell their commodities (in fact, given the market-power of buyers, the inflation-adjusted price of many crops has fallen), many farmers incurred significant debt in order to buy more land, more machinery, and other petroleum-derived inputs, and achieve greater economies of scale (Seccombe 2007). Of course, not all farmers were able to adopt this model of intensification, which produced a differentiation of farm structure and a squeezing-out of many farmers from the industry. For farmers to stay in production, concentration has created incentives to capitalize and significantly intensify cropping. These processes have simultaneously diminished the power that small and medium scale producers have in setting prices for their commodities (Winson 1993). In this way, the prices producers are receiving at the farm-gate for their commodities are not rising at a rate equivalent to the price of their inputs. Thus, farmer net-income has been declining over multiple decades.

This dynamic has contributed to the formation of highly oligopolistic markets. For instance, currently, the top three U.S. meat packers control 80 percent of the American beef market (Emel and Neo 2011). A recent agreement between ConAgra Foods, Cargill, and CHS to combine their North American flour milling productions into a single conglomerate, Ardent Mills, will give these firms control over a third of the U.S. wheat flour market (Food and Water Watch). Indeed, the four largest flour producers (Horizon, ADM, ConAgra, and Cereal Food Processors) already mill more than half of the wheat flour in the U.S. today.

Implications of rising connectivity for resilience

From a resilience perspective, rising connectivity primarily means that a smaller number of producers are providing a growing proportion of commodities along the food supply chain. Commodity concentration in particular can make the supply chain vulnerable to contamination and outbreaks in new ways. Additionally, concentrated production and supply systems demand that regulations are rigorous and reflect the scale and complexity of the process. However, such complex regulation is often not reflective of the conditions of small-scale production, or the resources and capital that small-scale producers have access to. Thus, concentration can often reinforce further concentration, making it very hard for small-scale producers to survive—even if they take great pride in farming, want to continue to farm, and want to gain fair access to down-stream markets. Concerning food system resilience, this trend means that while different food commodities certainly follow different chains and are hence not equally 'globalized', a growing quantity and proportion of food commodities are distributed along fewer, large-scale networks.

The impacts of a highly connected global food system on resilience is rather contextual, and dependent both on the region and threat in question. A dramatic example concerning the particular relationship between biophysical perturbations, vulnerability (in this case, food and

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[3] Although many scholars argue that concentration in the food system occurred long before the 1950's, a number of concurrent shifts caused concentration in the post-war era of food production to be both more comprehensive and more structurally transformative (Winson 1993).

political ‘security’), and global trade dependence occurred in 2010 and 2011. In the summer of 2010, drought and wildfires destroyed approximately 25 percent of Russia’s wheat crop (Kogan and Guo 2014). Conceding to popular protests, the Russian government halted wheat exports, which caused panic in commodity markets and drove wheat prices to historic highs. As a result of conditions in Russia, countries in the Middle East—who were dependent on Russian wheat—began experiencing significant declines in wheat supplies and rising food insecurity. Subsequently, food protests commenced across the Arab world. Events quickly became political, and today the Russian droughts of 2010 are seen as an important contributor to the Arab spring (Johnstone and Mazo 2011). This case shows that, for better or worse, recent history might have been quite different had the Middle East had not been as dependent on Russian exports (Johnstone and Mazo 2011; Kogan and Guo 2014).

While the Russian example illustrates the global hazards associated with high connectivity, ongoing food safety concerns in the U.S. spinach and Canadian meat production industries illustrate the national-scale vulnerabilities produced through rising connectivity. A study conducted by Miewald, Ostry, and Hodgson (2013) on meat safety regulation and production scale in British Colombia provides insight into the ways in which monolithic federal policy and regulation concerning food production and distribution can contribute to rising connectivity in the food system. Over the past decade, the industry has been deeply impacted by Bovine Spongiform Encephalopathy (BSE) and E. coli 157:H7 outbreaks, leading to significant meat inspection regulation reform along with numerous large recalls. After the BSE crisis hit British Columbia, the Canadian Food Inspection Agency rushed to adopt a highly prescriptive food policy that required all meat slaughter to be conducted at centralized, publically licensed plants. Predictably, this policy served to protect industrial, export oriented production against global fears of Canadian meat contamination, while enforcing impossibly onerous transport requirements on more rural, isolated, small-scale meat producers. The subsequent rise in concentration of meat production, slaughter, and processing throughout western Canada led to vocal struggles over food safety standards and system vulnerability. On the one hand, alternative and small-scale producers and advocates contended that, given the large scale and broad distribution inherent in concentrated industrial production systems, the risk of a widespread outbreak was high (Miewald et al. 2013). Hence, they argued that the shorter geographic distance between farm-slaughter-customer, which small-scale production and direct to consumer marketing provided, reduced risk along the supply chain (ibid). As such, proponents of more local food systems concluded that small-scale producers and their applicable distribution networks should be valued and supported within British Columbia’s regulation. Industrial production proponents, on the other hand, argued that centralized production allowed for more efficient monitoring and surveillance. In the end, the Miewald et al. (2013) study found that by opening up the policy (and the definition of ‘risk’ within the policy in particular) to include an appreciation for diversity of scale and distribution, both producers and regulators could facilitate flexibility in enforcement and reduce systemic risk within the meat production system. In effect, these amendments helped to build a more nuanced meat inspection policy that appreciated the role that different scales and methods of production and distribution had to play in buffering systemic risk.

This example is supported by research examining the relationship between the scale of food outbreaks in the U.S., such as salmonella in eggs and E. coli in spinach, and high production and distribution connectivity in the industrial food system (DeLind and Howard 2008). The spinach case study reveals that the scale of spinach production in the U.S., illustrated through the concentrated commodity chain that comprises the industry, is directly responsible for the spatial extent of the outbreak that affected over 26 states (DeLind and Howard 2008). The authors argue that although local and regional scale food systems are unable to produce such an outbreak, the state's role in capital accumulation and legitimation has caused a monolithic regulatory reaction that privileges the structure responsible—industrial-scale commodity chains, while harming alternative regional networks.

A second implication of rising connectivity is increased production risk. A number of studies conclude that corporate concentration and vertical integration have led to retailer preference for purchasing from large-scale, mechanized growers (Winson 1993; Marsden 1997). That is, there is a clear relationship between the size of processor and retailer, and the size and constitution of the farmer that they choose to form a contract relationship with. This has not only led to a number of concerns over food and ecosystem diversity, but it also entrenches producer dependence on fewer buyers. When oligopolistic markets and actors exist along the production and supply chain, the chain itself becomes highly vulnerable to perturbation: whether it is weather, price, producer mismanagement, or pestilence. For example, large, tightly packed monocrop systems—which facilitate easy access to thousands of a single variety of closely placed foods—are ideal conditions for pest and disease populations to develop. More specifically, a study by Winson (1993) uncovered that smaller processors found it unwise to purchase their entire product from a single grower within a single geographic region, and that while expanding suppliers may require slightly higher logistical and financial resources, it reduced the risk of losing their whole supply in the case of a perturbation. However, with increases in food system concentration and integration, the preference has been building for decades toward fewer, larger producers. The assumption here is that larger, mechanized producers have more access to synthetic inputs and technology to override perturbations, and still produce a decent seasonal yield. While this may be the case, it simultaneously produces a different set of production risks concerning connectivity and scale.

Third, highly consolidated food production and distribution systems hinge on access to relatively cheap and reliable fossil fuel energy. As the food system becomes increasingly globalized, distribution networks increase dramatically across geographic space. Within this system, the highly developed infrastructural, logistical, and technological resources of large transnational corporations make them well situated to move substantial quantities of commodities almost anywhere (Bonanno et al. 1994). The result of the globally connected food system is that it maximizes the spatial capabilities of distribution in a way that can be highly energy inefficient (Pretty 2008; MacRae et al. 2010). While some argue that economies of scale can counter emissions produced during long distance transport, there are many ways that local and regional distribution can also be made far more energy efficient (MacRae et al. 2013). Comparing distance itself, distribution connectivity contributes to what Van der Ploeg terms 'the institutionalization of unsustainability' (2006).

Decision-making autonomy

The third component of resilience that will be explored is decision-making autonomy. As noted in the first section, decision-making autonomy is relevant because it helps to identify the role of power and motivation in shaping socio-ecological systems. The causes of declining decision-making autonomy are rooted in elements of agricultural industrialization discussed in the previous two sections. Thus, to explore decision-making autonomy in more detail, this section will first present data demonstrating a decline in decision-making autonomy on the farm. Second, we will explore the implications of these changes for producers and the resilience of their production methods.

Evidence for declining decision-making autonomy

There are three key factors that illustrate that farmers today have far less decision-making authority than in the past. The first is what is known as the 'cost-price squeeze', which is defined as a process where agricultural production costs continue to increase while farm-gate prices remain stagnant. For instance, in 1960, the average price paid to U.S. farmers for a bushel of wheat was $1.74 USD (Farmdoc 2014). Accounting for inflation, wheat should cost almost $14 dollars in 2014. However, prior to the 2007-08-food crisis, wheat was being sold by farmers for $3.42. Even after the crisis, wheat prices have hovered between $4.87 and $7.77 (ibid). This trend is common across many agricultural commodities, especially those intended for high volume production, such as soybeans and corn. As such, the viability of these crops can only be captured through economies of scale, which has drastically reorganized the size and scale of North American farms. As a result of scaling up and increasing inputs at rising per unit costs, the average cost of production in the U.S. has risen sixteen-fold since 1914 (USEPA 2013). Even between 2007 and 2014, agricultural production expenses in the U.S. have risen steadily from $269.5 to $348.2 billion (Schnepf 2014).

The second key factor relates to the direct consequences of the cost-price squeeze on farmers: we are seeing growing farm debt and a general loss of producer power. In Canada, the average amount of farmer debt is twenty-three dollars for every dollar of net income (National Farmers Union 2010). Although debt in the U.S. farm sector is less pronounced than in Canada, U.S. farm estate debt (inflation adjusted) has risen from $120 billion in 1970, to approximately $170 billion in 2014 (USDA 2014).

Third, small and medium scale producers are increasingly dependent on a small number of powerful corporate processers and retailers to sell their products. This dependence makes the producer less likely to act in a way that may jeopardize their access to that singular market. Additionally, producers become less able to voice concerns about unfair terms and prices, or change their on-farm practices, as larger processors have a great deal of market power to retaliate. In this way, much of the decision-making control has moved off the farm and into other areas of the food system.

For instance, in the U.S. egg production sector, the processor often controls by contract both the flock supply to the hen houses as well as egg purchasing. Numerous cases have been reported of threats by powerful processors that they will not supply hen houses with a new flock unless the hen house abides by—what might be unfair—contract changes (Woodall et al. 2011). This has been examined, but not nearly resolved, in the recent Farm Bill. The impact of such relationships is dynamic in that a lack of viable alternative options further entrenches producer dependence on input, processing, and retail agribusiness.

Shifts in California tomato production help to illustrate the particular relationship between producer dependence and debt. As the California tomato sector became more concentrated, farmers were urged to scale-up and mechanize (Friedland et al. 1981). To pay for the necessary tomato harvesters, farmers went into debt. At the same time, these substantial capital commitments locked the farmer into specializing in tomato production, which merely reinforced consolidation. Not only did mechanized harvesting demand a large quantity of tomatoes to be produced, but tomato harvesters could only operate successfully with a particular variety of tomato, which reinforced specialization. Not surprisingly, large agribusiness processors sped this trajectory along through long-term contracts, which stipulated that they would only purchase machine-harvested tomatoes (Friedland et al. 1981).

Implications of reduced decision-making autonomy for resilience

The implications of reduced on-farm decision-making autonomy are critical to consider regarding resilience. In particular, under these conditions it is extremely difficult for the producer to engage in long-term strategy such as shifting toward more ecologically adaptive production systems. Specifically, the processes outlined here have reduced the capacity and scope of opportunity for some producers to make independent decisions concerning what they produce, how they produce it, and why.

In the U.S., smaller farms in many sectors (including: hogs, broiler chickens, sugar, processing tomatoes) are typically contracted out to agri-business producers and processors. This will often allow the larger contractors to grow at the smaller firms' expense, as poor contract negotiations and power imbalances lead to underpayment of producers (Emel and Neo 2011). The constrained choices that smaller producers face from the contractor can manifest in forced efficiencies of scale, dependency on particular technology packages that make farmers "vulnerable to output and productivity manipulation by agribusiness firms", as well as a loss of flexibility in enterprise choice (da Silva 2005). Regarding the first point, a hog producer, for instance, often has only two choices when securing a contract; they can either deliver a minimum of 10,000 pigs, or none at all. In this sense, some farmers have de facto been forced to 'go big or get out'. While this has shown to be financially beneficial for a small number of producers who have sufficiently industrialized, the decisions themselves are not made because they are the best option for the ecological system, the community, or even the producer in many cases, but rather for the actors with the control to demand such decisions. The result is the loss of capacity for small and medium sized producers to maintain their scale or make changes to production based on external stresses or perturbations; an essential element of resilience. In this sense, unequal contract relationships can bind farmers to a crop or livestock enterprise, where they are unable to adapt or diversify production to changing economic or ecological conditions.

For instance, while transitioning to a diverse organic system may be ecologically, economically, and socially desirable, the question is whether these producers can access the market under such concentrated power. In many cases, niche producers such as organic farmers can only reach a certain size before large corporations buy them up. For example, Cargill has purchased a significant portion of natural beef producers in the western U.S. through its collaboration with Meyer Foods and subsequent purchase of Dakota Beef (Cargill 2010; Woodall et al. 2011). These oligopolistic and monopolistic conditions may be undermining producer capacity for, and attention to the implementation of ecologically sustainable practices. In fact, Burch & Lawrence (2009) argue that given the nature of finance, the growing integration of agri-business and finance capital in the food system may further reduce the possibility of 'greening' agricultural production in the future.

Resilience in the North American food system

Overall, three key results stand out from this analysis. The first general conclusion we draw is that the North American food system is now, more than ever before, displaying certain characteristics of a vulnerable system. In particular, we note that changes in the agricultural sector have led to a system that is less diverse, more connected, and one where farmers have less ability to innovate and make changes than in the past. So while we currently enjoy an extremely productive system that results in a large quantity of inexpensive food for consumers, these benefits have come at a cost. Namely, we are concerned that the overall food system may be becoming much more rigid and thus vulnerable to external shocks such as those caused by bad weather or contamination. Given that the literature on climate change projects weather-related shocks will become more intense and more frequent in the next generation, the increasing vulnerability of the industrial food system is a serious cause for concern.

The second general observation we make is that although the framework used to guide this analysis is based on three key components, we emphasize that food system diversity, connectivity, and decision-making autonomy are all interlinked. These links can be illustrated by contrasting high-input methods of production with low-input agroecological methods. High input methods reduce the need for the grower to pay attention or respond to ecological feedback cycles in the agroecosystem. For example, instead of responding agroecologically to feedback cycles of soil erosion and excessive surface water runoff or leaching by increasing soil organic matter (and thus increasing crop diversity and incorporating forages and green manures), conventional producers are—both structurally and rhetorically—encouraged to simply change the Nitrogen-Phosphorous-Potassium balance of synthetic fertilizer application. The result is a agricultural system that is stabilized through significant investments in engineering, infrastructure, and policy, rather than agroecological system knowledge (Berardi et al. 2011).

As a result, the analysis presented here suggests that in many cases, producers may not have the same need or interest in encouraging agroecological diversity under the high-input system, since a few cash crops are what have been promoted to them. Relatedly, cash crops such as grains and oilseeds—which are mainly produced via industrial scale high-input systems in North America—are also the most heavily traded agricultural commodities (AAFC 2012). These production systems are thus contributing to highly connected and uniform transnational distribution networks as opposed to what are, in many but certainly not all cases, more heterogeneous and reflexive regional and local distribution networks (Born and Purcell 2006; Feagan 2007). While there are financial benefits to participating in consolidated transnational trade networks, the drawback is a reduction in localized capacity to adapt to perturbations. Finally, the relationships that both dictate and are created by industrial food production methods are highly relational. If neither the producer nor the agri-business input or processing firm need to autonomously adapt to perturbations, these relationships can be quite lucrative and easy to manage. However, as our discussion on decision-making autonomy has shown, these relationships can lead to systemic rigidity and inequality between actors, especially when power and scale differentials are great.

More generally, the infrastructure required for high-input industrialized production has created a system that operates beyond agroecological cycles. This is the essence of the industrial food systems vulnerability: if its engineering, infrastructure, or policy stabilizers were to be removed, the result would be far more devastating than that of a system which never had those stabilizers to begin with. Hence, in order to avoid widespread economic, political, and social catastrophe, many argue that those stabilizers need to stay in place (Juma et al. 2013). Indeed, the focus of industrial agricultural production is productivity and efficiency, bolstered by these aforementioned stabilizers. While the system has been effective from this perspective, banking on engineered stabilization leaves the system significantly vulnerable to perturbations that operate beyond the system's own bounds of ontology, epistemology, or control—i.e. unexpected or non-linear climate variability and feedbacks, extreme weather events, or unexpected ecological consequences of ongoing input application.

Our third observation is that the same forces of capital accumulation that led to farm consolidation and increased connectivity have also led to reduced diversity and decision-making autonomy. At the root of our critique, therefore, is a concern that de-regulated market forces (made possible through numerous re-regulations established to benefit capital) has created incentives that have traded off short-term productivity against long-term resilience. Indeed at the field-scale, the industrial food system shows evidence of declining resilience, while as a whole, the system exhibits features of resilience—via a steady supply of cheap food. Effectively, the types of production systems and methods that qualify as 'resilient' depend on *who* we include as the beneficiaries of resilience, and *what* the system ought to be resilient *to.* If we are measuring it through sustainability or climate change mitigation measures, increasing our use of synthetic inputs, and technological and engineering fixes have allowed us to hold agro-ecosystems at a point that many ecologists would consider to be highly vulnerable (i.e. 'an accident waiting to happen'). However, if we are measuring through efficiency, productivity, and stability measures, we might conclude that these same methods enhance resilience to economic inefficiencies or short-term production perturbations. We argue that the latter has been the goal of the food production industry for the past 50 years, and that the trajectory of this framework has resulted in a trade-off of long-term resilience for productivity and stability. In the context of climate change, where perturbations are projected to be more severe and frequent, we must question whether our 20th century fixes are likely to meet the problems of the 21st century.

Discussion and conclusion: moving food system resilience forward

Four key overarching issues stand out from the literature reviewed in this paper:

1. Policy should be directed toward creating incentives for more diversified farming systems.
2. While acknowledging the utility of agricultural trade, resilience will be enhanced if there is a greater degree of regional autonomy within food systems.
3. Increases need to be made to the degree to which farmers are able to act autonomously and choose management practices suitable for their farms. This requires that farmers not only gain political and economic power (see the next point) but also the skills and knowledge required to farm using more agroecological practices.
4. To achieve these ends, there is a need to correct power imbalances in the food system.

First, regarding on-farm diversification, it is clear that crop diversification, and shifts toward agroecological methods more generally, are not easy to transition into under current economic and political conditions. Farmers may ignore good agroecological knowledge if they lack the autonomy and power to implement the practices. Thus, policy and market changes are necessary to give farmers incentive to *apply* this knowledge. Food production diversification requires both a democratization of access to land, as well as a democratization of access to *relevant* markets. Many people who are interested in farming are barred from practicing due to unaffordable land prices and a lack of alternative ownership structures (such as public trust or cooperative models). Such structures should also prioritize land access for marginalized peoples in particular. If done effectively alongside training and extension services, democratizing land access will get more farms into production, ideally helping to reduce the rise of farm consolidation. Access to relevant markets implies both a political and cultural shift. Supporting diverse produce, grains, and pulses from agroecological growers requires a divestment from many of the industrial scale chains currently subsidized, and a re-investment in a host of new farmers, most of which will be small to medium scale. In doing so, it has been argued that greater economies of scale in regional distribution could be achieved, pushing prices of fresh, local products down over time.

Concerning revenue and crop supports, while they are important for producers, there are opportunities to focus this support on ecological practice and crop diversification, which exists in only a few small, underfunded, and relatively weak ways under the current system. Additionally, effective alliances between the food production and health sectors is already underway in North America, and ought to be expanded (Desjardins et al. 2009; MacRae et al. 2013).

Specifically, a 'multifunctional' approach to food production policy could help to encourage farm-scale diversification (Buttel 2003; Boody et al. 2005). A public multifunctional policy would provide incentives to farmers for adopting practices that generate a range of ecological and social goods and services on their farms. Seccombe (2007) argues that linking to health promotion programming would strengthen a multifunctional approach even further as it would encourage demand for fresh local products, thus supporting markets that are relevant to agroecological farmers. In addition to sustainability incentives, a tax or elimination of subsidies on chemical inputs would dissuade dependence and over-use (Tilman et al. 2002). Finally, independent regulatory oversight is necessary to help reduce the ecological damage caused by industrial agriculture such as the nutrient runoff from intensive livestock production. Tracking the cause of non-point source pollution is very difficult. However, if monitoring and tracking were done at a landscape or watershed scale, important insights could be made regarding the off-farm impacts of conventional agriculture. As a result, farmers and planners could work together at a landscape scale to restore ecosystems and develop buffer zones where most effective.

Second, while acknowledging the utility of food trade, resilience would be enhanced with more robust local food systems. This conclusion emerges logically from evidence illustrating the relationship between connectivity on commodity chains and health risk, demonstrated through the E. coli outbreak in U.S. spinach and the meat inspection case in British Columbia. In the B.C. case, we see that nuanced policy—which supports diversity in farm-size and facilitates policy application relevant to different agroecological scales, conditions, and locales—is possible and can lead to more vibrant local-regional food systems. Although we should not fall into a romanticization of the local, food policy would benefit from greater focus on the "context specific ecological and social factors global markets tend to externalize" (Feagan 2007). Pragmatically, this would mean increasing regional and local food infrastructure, distribution and provision programming, as well as increasing support for local agriculture, whether urban, suburban, or rural. These 'buffers' would hedge the risky degree of connectivity that geographically and commodity specialized production produces. More specifically, the aforementioned multifunctional credits could include an additional incentive favoring local producers over export markets. To be successful, greater risk management and support is needed to encourage farmers to grow diverse, locally demanded fruits, vegetables, pulses, and grains.

Additionally, public programming is needed to build better regional storage, processing, and distribution infrastructure (Baker et al. 2010). In doing so, regional distribution networks could be made more efficient, thus reducing the financial and energy costs to farmers for using 'alternative' networks.

Third, a number of studies have confirmed that adapting to climate change in agriculture depends a great deal on farmer knowledge and practices (Smit and Wandel 2006). For instance, Seufert, Ramankutty, and Foley's (2012) study on organic versus conventional farming systems shows that organic systems seem to depend more heavily on agronomic knowledge and management techniques than conventional systems. So, while high-input industrial methods largely just require consistent access to synthetic inputs, organic and agroecological systems (which includes organic) demand the grower pay attention to natural cycles. In this way, adopting low-input practices may not only have ecological benefits, but economic ones as well. Ecologically, the agronomic knowledge gained by low-input producers (whether defined as organic, sustainable, or biodynamic) may make them better equipped to respond to ecological change over the long term. Common agroecological methods to naturally balance nutrient supplies and reduce pests—such as diverse and companion cropping, planting green manure and cover crops, and integrating forages and perennials—help to build soil organic matter, thus making the soil better able to perform in drought and excessive rain conditions (Lynch 2009; MacRae et al. 2010). Strategically diversifying crops also hedges against pest infestation, as a single pest typically affects only certain crop varieties. In essence, achieving 'functional diversity'[4] at the farm-scale has been shown to build an agroecosystem that has a wider tolerance range to temperature and moisture variability, which is a system more resilient to climate change.

To do so, farmers would require access to a greater quantity and quality of information (from a wider diversity of interests) detailing these strategies, their benefits, and how they can be executed within different socioeconomic, farm-scale, and ecological contexts. Comprehensive farmer education and skill building for agroecological practices is possible through publically and community supported workshops, mentorship programs, and farmer-to-farmer training. Indeed, great hands-on work is already underway across North America[5]. However, commercial interests consistently dominate the political and discursive space, which leaves the few surviving public entities left struggling to remain relevant for producers, and thus following the lead of the dominant informational sources. As a result, most producers now receive their production information and build their agricultural knowledge from private, commercial interests. From this analysis, it is clear that agro-ecological knowledge and information has long been politicized for commercial interests. Therefore, strategies to repoliticize this knowledge toward producer, labour, and consumer interests, ought to be expanded within the industrial food system context, as being done through the food sovereignty movement. The challenges and complexities of building an inclusive and comprehensive food sovereignty movement are significant, but excellent work is already being done to confront and address these challenges (Burnett and Murphy 2014; Alonso-Fradejas et al. 2015; Brent et al. 2015).

Finally, the literature explored in this paper demonstrates that power inequities between actors in the food system need to be addressed before distribution networks can effectively

[4] Replicating the functions of natural systems in their applicable ecological context: i.e. establishing "species and mixtures of species appropriate to specific environments" (Jackson 2002). Jackson highlights the 'perennial polyculture' as a functionally effective form of 'natural systems agriculture' in prairie ecosystems (Jackson 2002).

[5] Especially through non-governmental organizations (NGOs), community groups, and neighborhood initiatives.

localize, and land and markets can be more openly accessed. While this includes actors from producers through to consumers, the scope of this paper means that attention will be paid to inequalities at the production end of the food system (between different scales of producers and between producers and corporate buyers and sellers). The efficiencies that agri-business can produce through economies of scale should be tempered by the inefficiencies they generate through excessive profit accumulation, barriers to market entry, and propagation of the externalization of ecological costs. In both Canada and the U.S., the government has been, and continues to be, ever-present in food system governance. It is merely *how* this governance transpires that has changed (for instance, what is typically considered 'de-regulation' is often in fact re-regulation toward market forces rather than the elimination of regulation outright). Beyond the normative concerns involved, it is a false assumption that government can ever just 'leave it to the market to govern itself'. We need to look no further than the direct payment system in the U.S. to argue that attempts to marketize a sector can end up subsidizing a small set of firms with the most power. In the food system, this has been agri-business processing and retail firms. Therefore, a *de facto* acknowledgement of the power imbalances present, as well as their capacity to manipulate markets, would benefit North American food production, inspection, and distribution policy. Instantiating market fairness, requiring greater transparency standards and exploitation checks for larger agribusiness contractors, supporting co-operation between small and medium scale producers, improving access to land for those historically repressed, and facilitating more collective approaches to scale-up production and distribution, offer possible steps forward. To commence this process, the state would need to meaningfully engage in critical reflection of their historical and ongoing role in shaping unequal and discriminatory land access policies, not only via class but race and gender as well. Industrialization, corporate concentration, and standardization in the food system have facilitated shifts in both power and practice. In the end, the policy goal ought to embody transformative shifts in system connectivity, diversity, and decision-making autonomy that improve ecological resilience on the farm, within the processing and distribution process, and throughout the food system as a whole.

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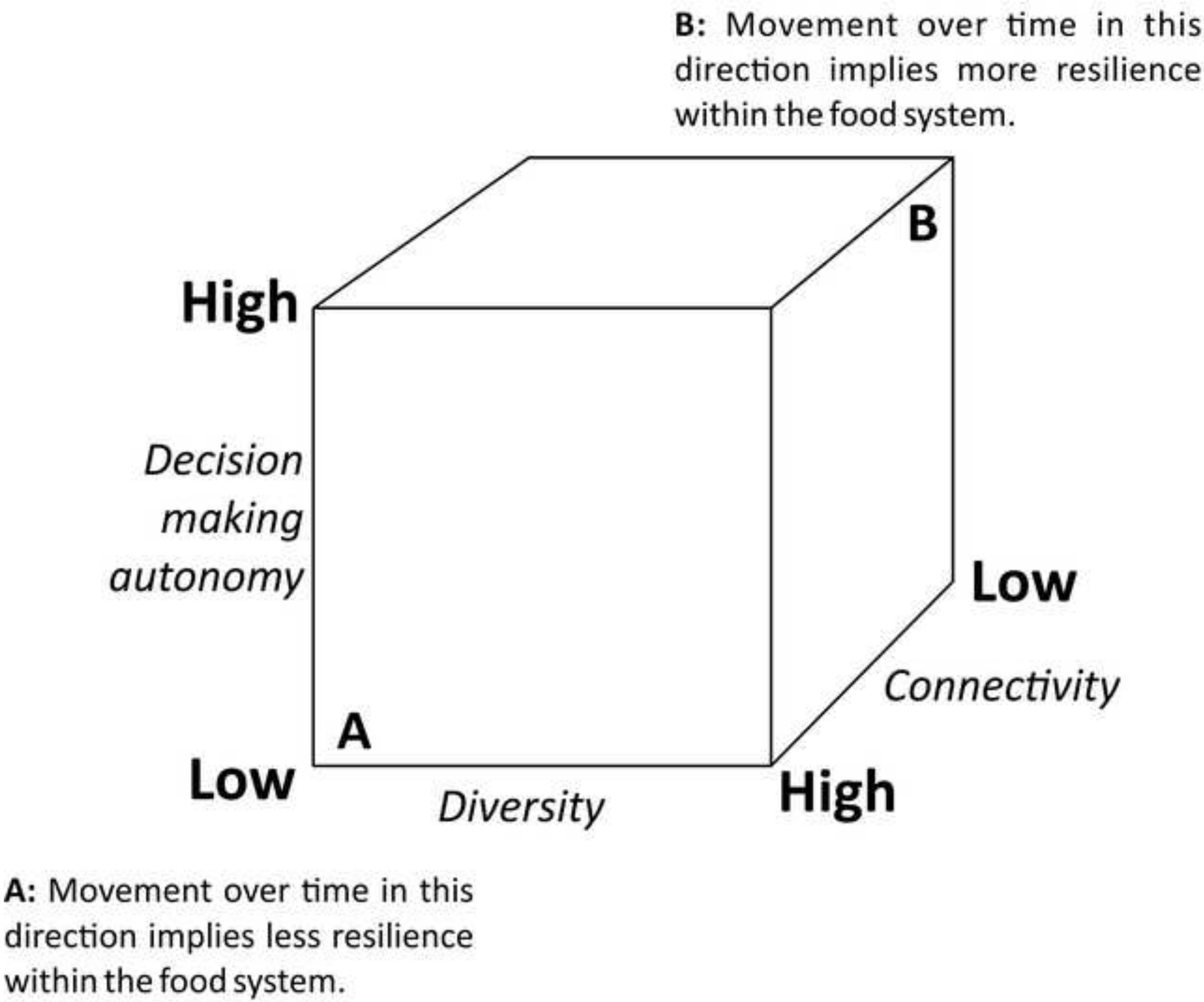
B: Movement over time in this direction implies more resilience within the food system.
B
High
Decision making autonomy
Low
Connectivity
A
Low
Diversity
High
A: Movement over time in this direction implies less resilience within the food system.