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Does the global food system have an Achilles' heel? How regional food systems may support resilience in regional disasters

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Abstract

Today's domestic United States food production is the result of an industry optimized for competitive, high yielding, and high-growth production for a globalized market. Yet, industry growth may weaken food system resilience to abrupt disruptions by reducing the diversity of food supply sources. In this paper, we first explore shifts in food consumption patterns towards reliance upon complex and long-distance food distribution, food imports, and out-of-home eating. Second, we discuss how large-scale, rapid-onset natural hazards may shape food access for both food secure and insecure households, given changing realities of consumption. We then consider whether and how regional food production might support regional food resilience. To illustrate these issues, we examine the case of western Washington, a region rich in agricultural production, but also threatened by a Cascadia Subduction Zone earthquake and tsunami. Such an event is expected to disrupt transportation and energy systems on which the dominant food distribution system relies. With limited household food stockpiling beforehand, and predicted difficulty moving food supplies into disaster-impacted communities, can survivors reasonably turn to food produced locally? The results of our research indicate that regional farm production, small in scale and flexible, can help support food security prior to the arrival of robust emergency relief. Yet, in order to do so, we need to have in place a robust, and regionally appropriate, food resilience strategy. This strategy will need to address caloric need, storage, and distribution, and, in doing so, re-balance our dependence on food supplied through imports and complex, domestic supply chains.

Keywords: food access; disasters; resilience; earthquake; Washington; small-grain cereals; regional food systems

Introduction

On any given day in the United States (U.S.), food appears to be plentiful, even overly abundant. This is the land of box store grocery market and discount food clubs that sell instant noodles in packs of two dozen at a time. It is also the land of fast food restaurants, with more fast food restaurants per residents than any other country in the world — 225 per million in 2015 according to *The Economist*. To supply it all, vegetables from California's bountiful Central Valley, staple crops of corn and soy from the Midwest, and dairy products from the northern and western states crisscross the nation. At the same time, a growing supply of imported food augments domestic production. While this abundance is far from equally distributed – swaths of the southeast and Appalachia have been highlighted as food deserts by the United States Department of Agriculture (USDA) – for most communities an abundance and a plethora of food choice is generally a given.

Yet, not all days are the same. On average, between the years 1960 and 2013, the U.S. experienced $12.1 billion in property losses and $2.8 billion in crop losses annually from extreme natural processes such as hurricanes, flooding, severe weather, landslides, tornados, and earthquakes (HVRI 2013). These geological and hydro-meteorological processes communities experience occur within historical, socio-political, and economic contexts that often exacerbate the natural process and create the infrastructure fragility and societal vulnerabilities that lead to heterogeneous geographic and temporal patterns of loss we commonly call 'disaster.' As such, disasters, and even the magnitude and frequency of some hazards, are never truly 'natural.' They are the product of a dynamic environment and human agency (Wisner et al. 2003; Oliver-Smith 1999; Steinberg 2000). Due to infrastructure fragility and social vulnerability, these natural processes regularly degrade, even halt, local and regional transportation, energy systems, and food distribution networks in affected communities.

The USDA defines food security as access by all people at all times to enough food for an active, healthy life (Coleman-Jensen, Gregory, and Singh 2014). Food security thus can be considered as access to a daily minimum amount of culturally appropriate calories. Food security is threatened when:

a) Civil conflict or limited access to food-producing resources, especially land, result in food deficits,
b) Natural hazards strike vulnerable population, whether that be a broad segment of a community or, more frequently, its marginalized members, or
c) Food quality is compromised, due to either a) or b) above, or to inadequate high quality and/or reasonably priced retail outlets.

Rapid-onset, large magnitude disasters may impair household access to food. Yet, little research to date has been done on changes in food access, with implications for food security, in the U.S. during the immediate emergency phase of disasters. Multi-year drought can radically reduce crop production in a region. Large magnitude floods and hurricanes may damage the storage facilities and distribution networks. Floodwaters, mixed with industrial waste and sewage, can directly destroy or contaminate food resources. Debris and silt from floodwaters can compact soil and leave fields unusable for years. Yet, often communities have sufficient warning – rising rivers and predicted hurricane paths – so that many households can evacuate to places outside the affected region in time or stockpile foods out of harm's way.[1] For rapid-onset events such as earthquakes and some landslides, which occur with little or no warning, damage to food supply and distribution can more directly impact food access for households at all income levels; households simply do not have time to stockpile or evacuate after they know the event will occur.

[1] Evacuation and stockpiling are premised on sufficient resources. For low-income households stockpiling and evacuation may be unaffordable. Households without private transportation must rely upon social networks or already overwhelmed public and emergency transport to evacuate. Many often choose to ride out the events at home, as was seen in New Orleans during Hurricane Katrina.

News reports from Hurricanes Katrina and Sandy in the U.S., reports from the 2010 New Zealand Christchurch earthquake, and limited research after the 2011 Tohoku earthquake and tsunami in Japan, offer some limited insights into how large, rapid-onset hazards may shape food access and purchasing behavior in the U.S.[2]

Following the Tohoku Earthquake, many residents experienced psychological anxiety, especially around the availability of food. A week after it struck, the Minister of State for Consumer Affairs pleaded with citizens to avoid hoarding. In the Tokyo metropolitan area, over 300 kilometers from the epicenter, Hori and Iwamoto (2014) found that consumers engaged in panic buying for a wide range of products, though actual shortages occurred only for a few items. Supply in the metropolitan area was robust, nevertheless panic buyers emptied shelves, triggering stress and panic purchasing in others. While empty shelves in Tokyo did not create actual food insecurity, the picture was different near the epicenter. In districts of East Japan, where damage to roads and power grids was pronounced, households faced serious supply shortages for many items in the chaotic weeks after the event.[3] At evacuation centers, survivors subsisted on rice balls and bread for many weeks, in part due to fears of radiation exposure through contaminated foods grown near the meltdown of the Fukushima-Daiichi nuclear plant (Belyakov 2015).

Following Hurricane Katrina in 2005, New Orleans and other Gulf Coast residents were similarly stranded, in this event by washed away roads, flood waters, and fallen power lines and trees. While meteorologists did provide early warning for this event, thousands of low-income, elderly and other New Orleans residents remained in the city when the levees failed and rapid-onset flooding began. With residents trapped in the city, both water and food supplies dwindled. Supply convoys headed to New Orleans took three days to first reach the city, at which point distribution to those in need was still necessary; specialized supplies took longer (Thomas and Mora 2014). Even after the emergency response phase had subsided, impacts on food access lingered. The number of New Orleans supermarkets dropped from 36 stores to 15. Residents without transportation relied more on local convenience stores, resulting in a drop in household consumption of fresh food (Mioses 2007). A multi-year study of supermarket access found that racial-ethnic disparities in access to supermarkets increased after the storm and did not return to pre-event levels for four years (Mundorf et al. 2015). Years later and two thousand kilometers north, "Superstorm Sandy" slammed into the northeast U.S. in 2012. Even with extensive early warning, supermarkets in coastal areas of New Jersey and New York threw out food supplies contaminated by the meter or more of storm surge many experienced (Taylor 2012). In the immediate aftermath of these events, retail food availability shrank and access to specific items was unpredictable.

The Christchurch earthquake offers another glimpse of how large-scale, rapid-onset hazards can reduce food security in urban centers. Following the earthquake, the retail outlets, warehouses, and stocks of commercial food retailers were damaged. Residents of Christchurch could not purchase basic food such as milk and bread and while supplies were brought in from other regions, the damage to transportation routes, including road, rail, and port facilities, slowed their delivery. Access to water also complicated food security. Eighty percent of the water system was severely damaged. For two months, many residents had no running water and relied upon water brought by tanker to centralized locations, a system that was not available in the immediate days and weeks after the quake (McColl and Burkle 2012). Computational modeling for Los Angeles provides further nuance and suggests that degradation of water supply has broader impacts than simply food security. A computable general equilibrium analysis of earthquake-induced damage to the California Aqueduct found that without aggressive conservation

[2] The World Health Organization and other United Nations agencies routinely complete rapid food security assessments of endemic and disaster-induced food insecurity in low-income countries. While crucial for humanitarian response to these events, the differences in subsistence, income, and spatial distribution of population make these assessments less useful for deducing disaster impacts to food access in the United States.
[3] A less extreme case of food shortage made international news when New Zealanders faced a shortage of Marmite spread several months after the 2011 Christchurch earthquake.

strategies, Los Angeles' economy would experience significant negative impacts due to loss of water for cleaning, cooling, and manufacturing, even for a closure as short as six months (Rose et al. 2012).

The specter of spoiled food, empty shelves, and constricted flow out of the kitchen faucet has prompted emergency preparedness public education for decades. These campaigns typically recommend that households store at least three days of food, water, and medication, though many emergency managers privately admit that a three-day supply may not be adequate in large-scale disasters. Two weeks of supplies — more in remote areas — is what they would rather see their communities stockpiling. But, it is not clear how many households in hazard-prone areas even meet the three day stockpile recommendations. One study sheds light. Thomas and Mora (2013) used interviews of 172 householders in Wellington, New Zealand to understand household water, food, and medicine stockpiles that might be available immediately after a large-scale earthquake. They found only 35 percent of respondents reported being prepared to survive for three days, though the researchers' own calculations of supplies suggested just over half of the households had sufficient resources for the recommended three days. While respondents reported that they would be quite likely to offer assistance to others, they indicated that they would be less likely to do so after a week of shortages and would be more likely to lie about their resources as the disaster continued. Respondents also indicated that, after one week, they would be willing to engage in novel and higher risk behavior around food and water access – taking water from unpurified sources and stealing essential resources.

Even with limited literature on the topic, the potential for large-scale, rapid-onset natural hazards to disrupt food access in the immediate impact zones is a concern. Communities at risk, which for the U.S. includes large swaths of the country, might rightly ask what can be done now to better ensure their food system remains resilient? How could access continue for all during such disruptions? We argue that part of the answer may lie in regional food systems.

Can regional food production help?

Much has been written about the "local" in food, but little in terms of food interruptions and the regional contribution to increasing food system resilience (Dubbeling 2013; Ruhf 2015). From previous research, we have found that, on a regional level, small- and medium-sized farms contribute substantially to food supply and economy, as well as model resilience (Hammond et al. 2013). Ruhf (2015) further argues that regional food systems are better drivers of resilience as they reduce dependence on external resources, such as are present in long-distance supply chains, and increase a nimble and flexible regional capacity.

We suggest here that interest in a regional agriculture should not be only the domain of self-proclaimed foodies, locavores, and small-scale producers. Certainly, all of these groups contribute to a vibrant regional agricultural economy, but we feel that the locavore topic has been well-covered in numerous other publications (Clancy and Ruhf 2010; Low and Vogel 2011), with Kloppenburg, Hendrickson, and Stevenson's (1996) "Coming in to the Foodshed," being a particularly insightful, early treatment of the subject. Yet, beyond these "true believers," people of all warp and weave have interests in adequate food access during crises, and in the foundational role such access will have in supporting community recovery. Whether a regional food supply – for the purposes of this paper, defined as food production in one or adjacent watersheds – can support this broader goal of community food resilience during large-scale disruption becomes a question of interest for all. The discussion that ensues in no way is meant to offer simplistic, localist solutions as the one answer to disaster food provision. Likewise, dismissing local food sources is similarly unhelpful to food planning processes. Rather, diversity of food sourcing can add redundancy and flexibility, allowing more nimble system adaptation in the face of disruption.

The purpose of this paper is threefold. First, we will explore shifts in food consumption patterns towards reliance upon complex and long-distance food distribution, food imports, and out-of-home eating. At the same time, food insecure households increasingly rely on food pantries, themselves supported by federal supplies trucked into a region in a complex food distribution system. Second, we discuss how large-scale, rapid-onset natural hazards may

shape food access for both food secure and insecure households, given changing realities of consumption, using the case of a future subduction-zone earthquake in Washington state as a point of discussion. Third, we consider whether and how regional food production, especially small grains, beans, and nuts, might support regional food resilience, at least in terms of calories (and, to a certain extent, protein) during disasters. Our results show that regional production and distribution should be considered prominently in national resilience planning, as an antidote to the actions of Federal agencies with an "almost incomprehensible web of sub-agencies whose ability to function in an actual crisis is questionable" (Endres and Endres 2009, p 407). Regional food production can support efforts at other scales —infrastructure mitigation at the state level and preparedness at the household level — to reduce the likelihood that households experience food insecurity in the 'gap' between when a rapid-onset hazard occurs and emergency relief has reached their communities. However, we will argue that these regional systems are a limited resource, if not combined with adequate regional storage and distribution strategies.

This article consists primarily of a review of published work on food imports, community food supply strategies, diet and consumption patterns, food industry and agricultural production data, and farm-to-food information. Initial research for this paper was conducted under a small Federal Emergency Management Agency grant for the purpose of analyzing food system resilience; we have expanded on that research here. We look at immediate and short-term food deficits resulting from quick-onset natural hazards, rather than ubiquitous and persistent vulnerabilities, which are the rightful concern of a welfare state, and the subject of important discussion elsewhere (Poppendieck 1994).

As Endres and Endres' (2009) suggest in their provocative history of U.S. food security, resilience planning is very much a function of regularly-occurring threats (much like disastrous airline incidents prompts greater safety measures). Fraser et al. (2015) further argues that state-sponsored strategies of strategic grain stores have buffered against food crises, especially for the poor, have declined in favor of market-oriented approaches that cloud assessments of food system resilience. In rapid-onset hazard events, a market-oriented approach may result in food insecurity for some households, an experience that can increase anxiety, risky behavior, long-term trauma, or lead to regional outmigration. For highly vulnerable individuals, such food insecurity may prove to be fatal.

We maintain that consideration of rapid-onset hazards and their impacts is a useful exercise for assessing food system resilience and that disaster scenarios can serve to push us in planning for increased resilience. An intriguing question is: Could extreme situations prompt communities to consider a greater regional reliance in more ordinary times? While we cannot provide definitive answers, the question remains an underlying theme of this work.

Declining resilience: changing patterns in food access

Domestic U.S. food production is the result of a competitive and growth-oriented industry. Most current growth comes from international market expansion, which includes the purchasing of entire farm operations, increasing contract crop production, and emerging proprietary companies operating abroad (IRS 2014). Increases in a company's market share usually have come at the expense of a competitor's loss of share, which has led to the consolidation of smaller farms and companies into larger conglomerates with high degrees of differentiation and centralized production and warehousing. According to the Internal Revenue Service, such concentration takes advantage of federal tax incentives (Berardi et al. 2011; IRS 2014). Nonetheless, this growth weakens community resilience by ultimately reducing the diversity and scale of food supply sources. This happens as smaller operations face heavy competition in pricing and declining profit margins against large firms.

In a globalized economy, regional agricultures are influenced by market forces as much as by factors of physical geography – e.g., climate and precipitation: wheat is typically grown under 20 inches of precipitation or less in the Great Plains, cotton and tobacco in the warmer areas of the southeast, dairy is found in cooler, northern regimes. An interstate highway system, preceded by the advent of refrigerated transport by rail, opened up production and

marketing channels throughout the U.S.; food moves easily from one place to another. The gradient is more economic than physical – food moves and is marketed as befits business plans of all scales.

It can be argued that food system resilience is decreasing in the U.S. in a number of different ways. At the consumer level, what and where households purchase food is shifting dramatically. Increasingly, households are moving away from relying on home-prepared meals to either eat out-of-home meals or more prepared and packaged meals in-home (Guthrie et al. 2013). As such, fewer households have adequate food (shelf-stable prepared foods and certainly less of cereals, beans, nuts staples) for use in disasters and during an unexpected interruption in food availability at retail grocers, discount warehouses, convenience stores, or restaurants. For households experiencing food insecurity, centralized food distribution through federal benefits and food banks has also unwittingly decreased resilience of this emergency safety net during disasters.

Household food consumption

In 2013, the USDA's Economic Research Services (ERS) reported total U.S. household spending on food at 1.4 trillion dollars. Half of U.S. household spending was on retail food purchases such as in restaurants (see Table 1). The other 50 percent of household spending was on groceries for home consumption from a variety of sources. U.S. households used only a tiny fraction of their food budget to purchase food at farmers' markets, through Community Supported Agriculture shares, or to make direct farm purchases. The reliance upon out-of-home meals has grown precipitously in the past decades. Expenditure on food away from home went from 26 percent in 1960, to 33 percent in 1970, and increased to above 40 percent by 1990. With significantly less meals eaten at home than in earlier decades, it is safe to assume households have less staples on hand for preparing meals — including fewer canned goods and smaller stores of grains, oils, and other basic ingredients for meal preparation.

Table 1. Percentage Breakdown of U.S. Food Purchases in 2013, Total Food Purchases Equaling $1.4 Trillion (based on various datasets, USDA ERS, food expenditures)

Food Purchase Type	**%**
Food away from home	50
Food stores	31
Other stores	13
Farmers, manufactures, and wholesalers	4
Home delivery and mail order	2

The shift in food consumption has also changed what is eaten at home. Today, much of home consumption centers on prepared foods (as indicated in Table 2). Sales of convenience foods, such as prepared meals, meal replacement bars, and frozen food, are increasing among dual-income households and consumers who are generally short on time, resulting in a shift in commodity demand (U.S. Dept. Commerce 2008). More prepared foods invariably means a greater dependence on processed cereal grains, such as oats, wheat, and corn, as well as highly-contested (due to environmental and nutritional arguments) soy protein and oils. For many households, food security is now defined, not by the full pantry, but by the availability of nearby prepared food, whether that food is handed to them through a drive through window, in a take-out order, or the packaged meal purchased at a nearby grocery store.

Table 2. Home Food Purchase Commodities in 2006 (based on US Dept. of Commerce 2008).

Commodity	**%**
Prepared foods	36
Animal proteins	23
Fruits and vegetables	17

Bakery products and grains	13
Dairy products	11

Meeting the increase in the demand for prepared foods is made possible by policy derived from the North American Free Trade Agreement (NAFTA) and General Agreement on Tariffs and Trade (GATT); many domestic food companies entered into alliances with foreign entities as a result of the enactment of this legislation (U.S. Dept. Commerce 2008). Food from Canada, Mexico, China, and India dominate U.S. imports by value, with imports from Mexico and China into the U.S. experiencing over 10 percent growth between 2000 and 2014. For all categories but meat and dairy, the USDA's ERS reports an increase in volume of imports (ERS 2015). Most dramatic has been the increase in sugar and candy, with a 19.9 percent increase between 2000 and 2013. The U.S. Food and Drug Administration estimates food imports into the United States have increased from 4.4 million lines in 2002 to 8.6 million import lines[4] in 2010 (National Agricultural Statistical Service 2013). These food imports, coming through U.S. ports of entry, now represent over ten percent of all food consumed by U.S. households, including half of fruits and vegetables and over three quarters of seafood.

The complex distribution system these imports represent, combined with a decline in household level food storage, means food security for many today is intimately intertwined with transportation, energy, complex supply chains, and regulation systems affecting delivery of both domestic and imported products. This food system relies heavily upon a transportation infrastructure that includes ports, interstate road and rail networks, and transportation fuel systems. A regional disaster that interrupts such systems – degrading or disrupting travel routes and ports of entry, or reducing access to fuels used in food transport – poses a direct threat to food system and community resilience, both in the immediate impact zone, but also further afield. This is especially true given that produce in retail grocery stores travels about 4,200 miles, on average (Weber and Matthews 2008).

Consumption in food insecure households

Even while the commercial food distribution system providing food access for U.S. households has become increasingly complex and reliant upon transportation and energy systems, a significant percentage of households rely upon non-commercial food distribution — food distributed through food banks and pantries. Where and when households experience food insecurity, these sites have been the traditional means of addressing the shortfall. Yet, an examination of emergency food distribution – food distributed through food banks and pantries – in Washington state helps illuminate the fragility of these supposed safety nets.

One in six Washington households, or 14.3 percent, was food insecure during 2011-2013 (Colman-Jensen et al. 2014). In 2013, 1.3 million individuals, equivalent to a fifth of the state's population, made 8.5 million visits to food banks and pantries in Washington state. On average, each client visited a food pantry 6.5 times in 2013 (WSDA 2014). For clarity, these statistics and programs are not associated with, nor do they include USDA's Supplemental Nutrition Assistance Program (SNAP), commonly referred to as food stamps.

While annual statistics about food pantry usage suggest a large ongoing food insecurity, a regional disaster is likely to swell the ranks of households seeking access to food through food pantries. Unlike the Wellington residents studied by Thomas and Mora, Washington state residents have not recently experienced a large scale disaster that would have spurred emergency preparedness and stockpiling of adequate food, water, and medicine. Furthermore, Thomas and Mora noted that seeking food aid in a disaster, such as queuing up for a bag of groceries at the local food pantry, is more highly associated with anxiety over running out of food than a true measure of food deficit.

[4] An import "line," whether it accounts for one or one thousand items, is a data element provided by an import broker.

Those more anxious about being prepared for disasters were simultaneously more likely to report increased preparedness and stated they would still seek out aid. An examination of the food pantry resources suggests this emergency food aid system may become quickly overwhelmed in a disaster.

Washington state has a highly centralized network of food assistance primarily relying on federal aid programs. Each month, food banks in Washington state receive and distribute over 554 truckloads of USDA food to over 126,000 families (WSDA 2014). USDA food, trucked directly to food banks, accounts for nearly a fifth of the food resources pantries distribute. The majority of the remaining food resources consist of food purchased or donated from retail outlets that also source through supply chains that bring food from out of state and out of country.

Food pantries are not unlimited sources of emergency food aid. Food pantries typically stock one to three days of food supply for their customary client base. Providing adequate nutrition to populations of various vulnerabilities during a regional, rapid-onset disaster would put significant added demands upon this resource, and reduce food access especially for low-income households who regularly rely upon pantry donations (Green and Cornell, 2014).

To highlight such issues, we present a disaster scenario below. However, it is important to note that not everyone is affected equally in a disaster. Those already at risk for adequate food supply will be at a proportionately greater risk. Such increased vulnerability necessarily needs to figure into the discussion.

Food access during a rapid-onset disaster: the case of western Washington

As discussed above, United States households are increasingly reliant upon a consolidated agricultural sector and low-priced food imports, supporting a shift in consumption towards highly processed foods, food consumption outside of the home, and imported seafood and produce. These changes, combined with the reliance of food insecure households on food pantries that source significant quantities of food from outside the region, affects food insecurity during rapid-onset hazards. We explore the implications of these changes by examining a very real threat — a Cascadia Subduction Zone earthquake — to western Washingtonian's access to food during the chaotic, immediate post-event emergency.

In the event of a subduction zone earthquake, entire areas of Washington, such as the western side of the state where over five million people reside, are vulnerable to food system disruption. A 1,000-kilometer-long fault, lying mostly off shore of the Pacific coastline where the Pacific tectonic plate is subducting under the North American Plate, is capable of producing a mega-earthquake – seismic events of magnitude 8.0 and above, which would be among the largest earthquakes ever experienced. Paleontological records indicate the last subduction zone earthquake occurred in January of 1700 and that such seismic events occur every 200 to 1,000 years, with an average return period of 500 years (CREW 2013).

A Cascadia Subduction Zone earthquake and tsunami event is considered one of the most severe potential disasters the state is likely to experience. Modeling of a Cascadia event estimates immediate deaths from earthquake shaking and tsunami inundation could exceed 10,000 across multiple states; direct economic losses could be upwards of $80 billion, depressing the economy of the region for decades (CREW 2013; FEMA 2015). This event dwarfs other nationally significant disasters, such as the 1994 Northridge earthquake in California, which caused $59.8 billion in direct losses (2006 dollars) and only 57 deaths. It is more comparable to the levee-topping Hurricane Katrina of 2005, which caused over $81 billion in property damages and killed over 1,500 people. However, the rapid-onset of the ensuing tsunami in the Northwest is expected to cause a dramatically higher number of casualties than even in Hurricane Katrina (GAO 2007).

Loss estimation modeling of a Cascadia Subduction Zone earthquake has been extensive and is the basis for regional and national emergency planning (FEMA 2015). Such modeling estimates shaking to last on the order of several

minutes, producing severe-intensity shaking along the coasts, with strong shaking within the populous Puget Sound Basin.[5] Of particular concern is the tsunamigenic potential of these earthquakes. A Cascadia Subduction Zone earthquake is likely to shift the seafloor upward abruptly, causing a tsunami wave to generate and close-in rapidly upon the Washington, Oregon, and British Columbian coastlines. The tsunami waves are expected to rise as high as nine to twelve meters by the time they hit shore; for Pacific Coast in Washington state, that timing might be as little as 20 minutes after the earthquake and would be insufficient for thousands of residents to evacuate.[6]

The earthquake and tsunami are expected to further trigger landslides and ground failure throughout the region, especially in mountain passes and in the steep mountain valleys of the Cascade and Olympic mountain ranges.

Population impacts

A daytime subduction zone earthquake is expected to injure over 20,000 people in Washington and Oregon, with further injuries expected once the tsunami arrives and aftershocks, fires, HAZMAT releases, and contaminated water supplies take their toll.[7] Altogether, medical facilities might experience a surge of as many as 30,000 injured survivors, many of whom would arrive at hospitals that were too damaged to administer care from within the facility. Injury, especially combined with exposure to inclement weather, would leave many residents weakened and less capable of physically adjusting to a period of food insecurity (FEMA 2015; Woods and Schmidtlein 2013; Woods and Soulard 2008).

Modeling of a Cascadia Subduction Zone earthquake and tsunami event suggests poor access to clean water as well as to usual and customary foods. It is quite likely that the Federal Emergency Management Agency would not deliver emergency food rations for at least a week, based upon emergency response in similar disasters discussed earlier. First served would be those along the populous I-5 corridor. Out-migration from coastal areas to urban population centers is quite possible, save for tribal and rural communities with strong cultural connections to their homes. As given in this scenario, water would be severely compromised and food available would be marginal. Decades ago, households may have relied on partially-cooked canned goods, as well as dry, packaged items in pantry stores. The changes in household food consumption patterns noted above make planning assumptions that most households will be able to be food self-sufficient for a week or more after a rapid-onset disaster increasingly inappropriate. Widespread food insecurity is a more likely reality. Although healthy adults may be less affected by a week or more of food insecurity,[8] vulnerable groups (children under five, pregnant and nursing women, malnourished and diseased, the elderly) may be especially vulnerable (WHO 2000).

Infrastructure impacts and implications for food distribution

[5] The loss estimates discussed are based upon 90th percentile damage estimates — indicating a damage state with only a 10 percent estimated change of being exceeded. This worse case credible scenario is used for regional planning purposes in Washington and Oregon and helps to account for secondary impacts of landslides and aftershocks not well modeled in the loss estimation program.

[6] Tsunami wave heights are expected to be much smaller and less damaging by the time they reach Seattle, Tacoma, and other urban centers within the Salish Sea; Vancouver Island will refract much of the wave energy back out into the Pacific Ocean basin.

[7] Loss modeling of injuries is based upon the time of day. Earthquake events that occur in the middle of the night tend to cause the least injury and death in the United States, as most people are in the relative safety of their homes. Events that occur during the daytime, especially during commuting hours, are expected to increase injuries by an order of magnitude or more.

[8] Existing observations of survivors of famine and concentration camps and other extreme events indicate that most healthy adults can survive without food for approximately 30 days and without water for several days (Packer 2002). While it is comforting to think that few healthy adult would die from lack of food access in a Cascadia event, the aim of community disaster planning around food security should be ensuring survivors do not experience a dramatic increase in food insecurity during the immediate aftermath and recovery from these events.

Seismic shaking and ground failure are expected to severely degrade the region's transportation systems. Over a quarter of Washington state's road infrastructure is expected to suffer medium- to high-damage, meaning at a minimum, large cracks and ground settlement, and at the extreme, failure of pavement structure and subsurface materials. Highly damaged roadways may require major repairs before vehicular traffic can resume, a repair that is estimated to take months. Of particular concern in Washington state is the lack of redundancy in its network of highways. The mountainous geography has limited east-west transportation corridors and is limited to a handful of alternatives. A single major highway, Interstate 90, crosses the Cascade Mountains; six smaller east-west highways also cross but all would be compromised in the immediate aftermath. One pass routinely closes the entire winter and the others pass through steep valleys and ravines and would experience landslides that choke off transportation access for both roadway and railway. A single north-south highway transportation corridor, Interstate 5, connects all major population centers on the west side of the state and would be damaged. Loss estimations indicate that up to two-thirds of the interstate may suffer damages that seriously degrade or prevent transportation movement. The smaller U.S. Highway 101 along the Pacific Coast would be expected to suffer even higher levels of damage from the tsunami and be virtually unusable. Communities along the coast could be cut off by land from the rest of the state for weeks and months. Heavy, irreparable bridge damage is expected at 10 percent of bridges, including highway overpasses, in the populous Puget Sound Basin, and perhaps 50 percent of bridges along the coast (FEMA 2015).

Significant and prolonged degradation of the state's transportation infrastructure would be coupled with serious impacts to port facilities. Ports are typically built on unstable marine sediments and infill and are exposed to tsunami impacts. All state ports are expected to experience moderate to heavy damage. Piles supporting seawalls may be broken or damaged; cranes used for moving cargo between vessel and trucks or rail may topple. In highly damaged ports, expected to be the majority in the state, cranes may totally derail and warehouses may experience significant damage. The earthquake impacts are expected to result in partial or full failure of the docking facilities, rendering many residents virtually stranded (FEMA 2015). Such impact is significant – ferries, connecting the state's many island communities, carry approximately 22 million people and 10 million vehicles annually, and a disruption in service would be widely felt..

Transportation degradation — affecting road, rail, and port links — likely would impair replenishment of retail foods and other goods. However, it will likely also slow restoration of the electricity and natural gas households typically use for cooking food. Vast swaths of western Washington are expected to fall into complete blackout minutes after the earthquake as substation and distribution circuits fail and relays shut down power due to system overload. Repairs to transmission lines may take weeks to months; line crews will have to wait for emergency transportation crews to clear roads and shore up bridges and overpasses on critical routes before they can reach damaged substations and downed lines. Similarly, natural gas repair will require a minimally functional transportation system. Households may have their gas lines shut off for days in the Puget Sound area and for weeks to months in harder hit coastal communities (FEMA 2015).

Damage to water and waste water systems may also have immediate impact on survivors' food security. A majority of potable water systems in western Washington are estimated as likely to experience major damage, including complete failure of pipelines, extensive damage to treatment plants, and damage and collapse of water towers. Contamination from damaged wastewater pipes is expected throughout the region. Piped potable water may be unavailable for weeks to months, especially along the coast (FEMA 2015). Like in the Christchurch earthquake, urban households may initially have to boil contaminated tap and surface water, which will require a fuel source, during the first weeks of the disaster. They then will likely need to rely upon potable water trucked to distribution sites for months thereafter. Rural households relying upon well water may retain access to potable water if they have manual pumping capacity or a generator and sufficient fuel. However, unpredictable shifts in water tables are common after earthquakes; some wells may go dry while new springs may emerge elsewhere.

Here, we examine options for food security during the immediate emergency period in the days and weeks following a Casadia Subduction Zone earthquake and tsunami. For the purposes of our discussion here, water is assumed to be available, though likely contaminated. Loss of, or only sporadic access to, electricity and natural gas is also assumed. Transportation networks are assumed to be highly degraded, with bridges and overpasses damaged and landslides and debris blocking many roads. In dense, urban environments, a patchwork of surface and arterial streets may quickly be cleared, allowing for repair and partial restoration of power and resumption of delivery to many food outlets after the first week. In rural areas and along the coasts, transportation repairs, and with it repairs to power distribution systems, may take several weeks. These assumptions are in line with current emergency planning for a Cascadia Subduction Zone earthquake and tsunami. However, damages and restoration times used for planning are based upon complex probabilistic calculations; actual damages and restoration may vary substantially in an actual event.

Regional food for increased resilience

Food access during emergencies serves two functions: it prevents individuals from declining into an emergency health situation and reduces the likelihood of mass migration out of the region. Mass migrations of individuals to a new area can compound a disaster by placing new burdens on an area that does not have the infrastructure to handle the increased capacity, ultimately compounding or creating a new problem. Mass out migration can also have long-lasting effects on the economy, recovery, and culture of a region (Hobor 2015). Looking at Washington state as a whole, and with approximately 20 percent of Washington households relying on emergency food assistance programs, the potential for health impacts or migration could be significant.

With degraded transportation and energy systems expected in a regional subduction zone earthquake, regional food availability and an organized storage and distribution method takes on a critical new importance. Food that can be immediately accessed in the area may be more accessible than food sourced from outside western Washington, which would be reliant on badly damaged, long-distance transportation routes across the Cascade mountains, along the I5 corridor, or through coastal seaports. These local food sources may help supplement conventional food sources, such as undamaged packaged food on the shelves of retail outlets at the time of the disaster, shelf-stable food in home pantries, and the initially slow trickle of emergency relief supplies brought in by air or on a patchwork of less damaged roadways. Yet, the availability of high-volume, regional food stores is uncertain.

Estimating of population need

To begin to determine the adequacy of regional food resources during a disaster, population needs must first be understood. Short-term and immediate food deficits would be in cereals (rice, cornmeal, or flours) and a concentrated source of fats or oils; salt and sugars could increase palatability of all items. Basic nutritional needs would require the provision of about 1700 Kcal of food per day, at least 20 percent or more of which is fat (Seneff et al. 2011). Estimating food deficiencies in the immediate aftermath then depend upon household food stores, retail and food bank stock, the size of the vulnerable population, and the length of time before emergency relief supplies may begin to reach affected communities. Such calculations, if they have been done at all, are not publically available.

As a rough estimate, we can assume grocery stores and food banks have three days stock and that emergency relief supplies may take an additional 5-10 days to reach affected populations, leaving a 2-7 day gap. Many households will have some undamaged, non-perishable food stores and may be able to retain food security, albeit with a less varied diet. Some households that rely upon frequent purchases of food may dip into food insecurity when retail food stocks at stores and restaurants fail to be readily replenished. A portion of 20 percent of households who experience food insecurity each year may struggle to do so. With over 160,000 individuals visiting food banks each

week in the state, we can assume at least this many, if not significantly more, may have little access to food after the first two days. Those numbers will swell as households that normally rely upon frequent retail food purchases find those sources less available. Even well stocked households may find much of their food at home is unusable after a large earthquake. Without electricity or backup generators, food in refrigerators and freezers will begin to spoil, depending on outside temperatures. Preserved food in glass jars is also likely to fall off shelves and break. Perishables at local stores shelves will likely fare a similar fate, unless stores have on-site backup generators and sufficient fuel; broken glass will also litter the floors and force stores to close temporarily.

As a first order estimate, Western Washington may have 1 out of 5 million residents facing several days of food insecurity after they have used up their existing supplies. Together, these populations may need access to 4.8 billion Kcal of food before robust emergency food relief and restocking is widely available (see Table 3). Low-income households and physically vulnerable individuals in rural areas may be most at risk due to sluggish emergency transportation repairs in remote areas.

Table 3. Potential caloric needs of western Washington population in the immediate aftermath of a subduction zone earthquake

	Population	Kcal	Days of Food Insecurity	Total Kcal
Food Insecure at time of event	160,000	1700	5	1.4 billion
Heavily reliant upon retail food availability	1,000,000	1700	2	3.4 billion
				4.8 billion Kcal

Regional food production

With the scope of the deficit defined, we can then turn to identifying food production, processing, storage, and distribution resources throughout the impacted areas. In 2012, Washington had approximately 40,000 farms with a total agricultural production of about $10 billion in sales (Nat. Ag. Statistics Service 2012). The top five non-meat food commodities, comprising over 50 percent of the state's agricultural output, are apples, wheat, milk, potatoes, and cherries, as shown in Table 4.

Table 4. Percent of Market Share of Top Washington State Agricultural Commodities in 2012, by Value (Nat. Ag Statistics Service 2012)

Top Commodities	**%**
Apples	24
Wheat	13
Milk	13
Potatoes	8
Hay	7
Cattle	7
Cherries	5
Nursery	3
Grapes	3
Pears	2

Other fruits and vegetables	5

Washington also is a major producer of hops, stone fruits, farm forest products, aquaculture fish, shellfish, onions, and mint oils. Such output represents a diversity of commodities. But, with much of supply going to the export market, this suggests little of Washington state food security. In fact, according to the USDA, Washington is the third largest exporter of agricultural commodities in the nation, exporting $9.3 billion in 2007 and $16.5 billion in 2012 (Nat. Ag. Statistics Service 2013). Further, the USDA reports that approximately two-thirds of all farm exports are destined for Asia, with approximately 15 percent headed to Canada.

Despite Washington's sizable farm exports, 14 percent of farms in 2007 sold directly to consumers, restaurants, or retailers in Washington state, according to self-reported farm data collected by the U.S. Department of Agriculture's National Agricultural Statistics (Wa. State Dept. Health 2012). In contrast, according to the USDA's ERS, across the nation direct-to-consumer sales accounted for only 0.4 percent of total agricultural sales in 2007, up from 0.3 percent in 1997. It is not surprising then that Washington ranks seventh in the nation for having the most direct farm sales and second nationally for population-size-to-dollars-spent on direct farm sales. Perhaps the economic and social infrastructure is well in place for acknowledging regional produce as a resilient food source.

Physical and economic resources (not to mention marketing) in Washington state help to account for such a large percentage of direct sales. Certainly, established and respected programs such as farm-to-school, farm-to-hospital and other institutions, community-supported agricultural share purchases, and farmer markets provide important outlets for farm produce. Nevertheless, food system resilience is in jeopardy; we rely heavily on imports, much of what we eat is pre-prepared, and many rely, at times, on federal provisions through food pantries — all of which suggests that an interruption to transportation and energy systems would represent a substantial disturbance in usual and customary eating.

While a statewide assessment suggests high quantities of food are produced and stored in Eastern Washington — stone fruits, grains and potatoes produced on the Columbia Plateau and wheat and legumes on the Palouse — transporting these food items, as well as domestic food from out of state, to affected communities in Western Washington may be hampered by bridge damage and landslides in the passes and along the I5 corridor. Regional food, especially food produced and stored in the immediate vicinity of affected communities, may be more easily transported via smaller vehicles along a patchwork of functional, surface roads.

Recognizing that our customary reliance upon long supply chains, which depend upon functional transportation and energy infrastructure, is in doubt, we next turn to existing food supplies available at the regional scale. Certainly, continued promotion of household storage of non-perishable food and water for use in emergencies is essential, especially food that can be readily eaten without cooking and that is unlikely to be damaged during the shaking. Yet, the trends towards increased reliance upon out-of-home food expenditure and the significant number of households already food insecure and relying upon food pantries suggests this solution alone is unobtainable. Could regional food suppliers help provide the population with 1700 kcal per person daily, with significant protein and fat content, immediately following a rapid-onset disaster such as the one we describe? The answer rests with both regional food production and distribution prospects, as well as with potable water and adequate fuels available for cooking.

No centralized database or agency tracks local food production and storage, but certain sources provide some information on regional food resources' availability and distribution. Many counties, for example, Snohomish County in Northwest Washington no longer has large cooperatives for packing and processing. Would current production suffice? For example, does the dairy in Whatcom County or the green peas in Snohomish or the potatoes (most of which are used for seed) in Skagit put each of these counties on the map as a potential source of calories – either during an incident or throughout the year? It seems unlikely, both because quantities are insufficient and

seasonal variability in availability. More likely sites, for example, would be seafood processors in Anacortes and Bellingham, Washington, and those more centrally located along the I-5 corridor in Skagit County such as Americold, Commercial Cold Storages, and food distributor Food Services Inc. Together, five seafood processing and cold storage facilities in Skagit County hold an estimated 100 million calories combined at any given time. These cold storage sites may be an immediate source of calories, independent of season, though they make barely a dent in the potential need. Thus, we must turn to sources that are more novel.

From a regional foodshed perspective, one source of protein-rich fat is hazelnuts, which also are rich in fiber, as well as monounsaturated fatty acids, tocopherols (Vitamin E compounds), squalene (important in the synthesis of sterols), and phytosterols.[9] Small grains is another source of carbohydrates and protein (Maguire et al. 2004), and include wheats, perennial wheat, and other perennial cereal crops. Both hazelnuts and grains are easily stored. A single cup of whole hazelnuts with a cup of whole, dry grains can provide almost 800 kcal. Focusing on wheat certainly makes sense as it is (now) an almost universal cereal crop worldwide, and increasingly so in the Pacific Northwest as new winter wheat cultivars adapted to Washington state are being developed (Hayes et al. 2012; Hills et al. 2013; Jakumar et al. 2012; Jones 2012). The question germane to this article is, could these cultivars be grown on such a scale as to increase ecological sustainability of area farms, but also economic sustainability in terms of short-term immediate food assistance? It would seem that short-term needs, in terms of high-protein calories, could be provided for periods up to one week in western Washington in the face of a disaster – 30-50,000 tons are grown each year in Skagit and Whatcom counties alone, and dry beans, also, are becoming much more prominent (WSU Research and Extension Center, personal communication, May 28, 2015).[10] Can we produce high volumes of staples regionally? The answer is a qualified yes.

Prospects and challenges of regional distribution during disasters

While regional staple production is feasible, fuel, storage, and delivery are germane to making these sources a real possibility in a disaster. Any reliance upon unprocessed local grains and nuts as an immediately useful food source would be predicated on households boiling water and preparing food on open fire or portable, gas cook stoves and grills. For many rural and suburban households in western Washington, this requirement may be within the realm of possibility; for others, such as urban apartment dwellers, the requirement may be more problematic.

Also important to consider in terms of food delivery is the concept of 'emergency relief chains,' i.e., links between customer services and non-profit, non-routinized supply chains. Are regional farmers a good and reliable source of supply during food security threats? Examples attest to the ability of regional food networks to provide scheduled food assistance, such as school lunch programs (Sanger and Zenz 2004). In terms of short-term relief, infrastructure and relief program organization remain challenges. Better understanding of what motivates such 'chains' in a humanitarian context is needed (Oloruntoba and Gray 2009). Further, a more empathetic distribution system would also prioritize palatability in terms of usual and customary foods.

Infrastructure is indeed fragile, and a resilient food supply chain would need to address such transport and delivery challenges as described here. Yet storage facilities throughout the western part of the state could easily accommodate small grains. In this case, it seems the limiting resource to such scheme is political will. According to the Washington State Department of Agriculture, while there are no formal agreements or contracts to ensure continuity of fresh produce deliveries (from local sources) during disaster situations or in case of a major supply

[9] Note that virtually all the hazelnuts in the U.S. are produced in Oregon as reported by the Agricultural Marketing Resource Center and USDA ERS statistics on fruit and tree nuts, although Washington state is gaining ground. Hazelnuts in Oregon would necessarily better support affected communities in that state.

[10] Informed consent was obtained from all individuals interviewed as part of this article.

chain disruption, plans are underway to change the situation. Big, nonprofit storage facilities are growing throughout the state, and so is their storage capacity. This is mostly for commodity foods, i.e., foods distributed under federal assistance such as The Emergency Food Assistance Program, but assuming storage capacity increases, nuts, grains, and beans as mentioned above, some derived from farmer-distributor direct contracts, could be stored in turn.

Big storage projects already underway in western Washington include Thurston County Food Bank and Northwest Harvest and Food Lifeline in King County (Wa. State Dept. of Agriculture, personal communication, May 28, 2015). These organizations already work with local farms and manufacturers to identify food waste situations, arranging to have nutritious food that would otherwise be discarded be redirected to food banks.

When queried about supply chain disruptions, a Washington State Department of Agriculture representative stated that scenarios with such consequences have been analyzed by its Emergency Preparedness group and although delivery time would be increased, there are both land and sea routes to deliver products within a few days to most of the state. One notable exception would be moving supplies to counties south of Puget Sound, where I-5 disruptions would seriously impact delivery (Wa. State Dept. of Agriculture, personal communication, May 28, 2015).

A proactive approach and emergency plan could be developed to bolster a local food strategy to help minimize impacts of a supply chain disruption. Such an approach could include entering into agreements or developing emergency contact frameworks for farms, manufacturers, and warehouses capable of providing significant calories and flexible enough to redirect or change their operations. Developing contacts or interagency agreements with appropriate agencies such as the US Food & Drug Administration and Washington State Department of Agriculture to facilitate negotiating contracts with existing firms would support this effort, as would identifying and developing grant programs with USDA for increasing support to small and medium sized farms, increasing both production and providing marketing services for their products (Green and Cornell 2014). Yet, these step would only address issues of caloric access: they would boost the availability of grains, nuts, and other raw ingredients in close proximity to the affected population. To make these local sources functionally available, households would need to be advised how to cook or process grains, legumes, and nuts; increasing palpability through adding salts, sugars, and spices may also need to be addressed. For households without access to cooking fuel, neighborhood-level ‘soup’ kitchens may provide immediate and ongoing relief. Food pantries may be an ideal location for large-scale cooking and distribution of local foods.

One final note is that due to prohibitions on use of federal monies, food stored in contracted warehouses, such as food banks, may not be used for disaster-related assistance during an incident until authorized and most likely would remain intact at the distribution center initially. The Washington State Emergency Operations Center would be responsible for making this decision and communicating to the county food banks an issue for general aid, and then the state would be reimbursed at a later date.

Conclusion

Multiple and diverse food sources and distribution channels are important for building resilient regional food systems able to support communities in the immediate aftermath of a rapid-onset natural hazard. For Washington state, the current trend of manufactured, ready-to-eat foods, and increasing food imports places a profound importance on the transportation infrastructure. Any scenario that degrades transportation networks would do more than reduce food on grocery store shelves. Degraded transportation also would drastically hamper emergency food assistance programs that rely overwhelmingly on USDA-supplied and other manufactured food originating outside the region. While a rapid-onset, hazard like a Cascadia Subduction Zone earthquake and tsunami is unlikely to produce severe and prolonged food insecurity for the vast majority of the population, many households in the region could experience a food ‘gap,’ running out of food before emergency relief efforts and restocking have fully reached them. Such a gap is unlikely to cause widespread fatalities, hospital damage and exposure to wet and cold weather

are more troublesome in that regard. However, even short-term food insecurity can increase anxiety, lead to risky behavior, and prompt widespread outmigration that can overwhelm receiving communities or have long-term impacts on regional recovery.

Ensuring food security even during the immediate aftermath of a major natural hazard should be addressed by a myriad of overlapping mitigation and preparedness actions. At the state level, continued funding of transportation retrofitting, especially bridges and overpasses along critical routes, will strengthen the regional transportation network. A strengthened network will require less repairs and allow conventional retail and emergency food to reach impacted communities more quickly. It will also speed repairs of electrical, water, and natural gas networks. At the household level, emergency managers and community organizations needs to continue to encourage households to store (and secure) non-perishable, ready to eat food and sufficient water, reminding them that grocery store stock and the out-of-home eating on which they are increasingly reliant may be intermittent or unavailable for days, even weeks, after a Cascadia event. Households should be encouraged to slowly build stockpiles of food and water, enough for several days, even up to several weeks. These approaches are well known, but we argue that they should be augmented by regional actions.

Regional, diverse agriculture is part of the answer to post-disaster food security. It may help fill the 'gap' between the end of household and retail stocks and the arrival of robust emergency relief. Yet, in order for local foods to provide significant calories in a crisis, we need to have in place a robust, and regionally appropriate, food resilience strategy. This needs to be a strategy that re-balances our dependence on foods supplied through imports and long supply chains, as well as increasing our reliance on regional food sources. A regional food resilience strategy could be strengthened by diversification in agricultural fields, but would need to be augmented by a regional storage and adaptive distribution strategy. It could be supported by greater public awareness and policy in support of healthier diets. Such diets could include, in addition to fruits and vegetables, whole grains, dry beans, and tree nuts – as discussed in this article.

Currently, with the limited number of small and medium-sized farms surrounding urban areas, regional farms would likely be unable to support a long-term disaster due to diverse diet needs and nutrition requirements in communities. However, production of storage-able crops such as grains, beans, and nuts could contribute to food resilience strategies. Already, researchers at the Washington State University Mount Vernon Research Station are working to promote widespread regional production of small grains and dry beans.

There is untapped potential, however, for regional farms to contribute a significant amount in the interests of food system resilience if the appropriate frameworks and infrastructure were to be implemented. Under the current model of emergency food assistance, independent non-profit organizations are critical in developing a new framework since they are more flexible in arranging with growers, who may be hesitant to work with government agencies. These independent non-profits generally have fewer policies restricting cooperative arrangements, as well as less bureaucracy, so they can achieve more timely results.

Much has been written about the "local" and "regional" in food, but little in terms of food interruptions and increased food system resilience. Could extreme situations suggest the need for greater reliance in more ordinary times? The results of this research indicate that the potential for a greater contribution of regional farm production into mainstream supply, especially in the interests of food system resilience, could be substantial. This is the case especially in a state like Washington, where direct sales, indicative of support for regional production, currently constitute such a large percentage of the total food market. Greater reliance on local sources of food, in and outside disasters, may increase regional food resilience.

Compliance with Ethical Standards

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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