Episode 7 – Food Shocks and Resilience in the US Food Supply

Narration: What does the study of biodiversity have to do with our critical supply chains of food and other vital commodities? Could it help us prepare those supply chains for future shocks – like drought, covid 19, or a sudden geopolitical crisis? Find out in this episode of Crucial FEWSION.

Ben Ruddell: I'm Professor Ben Ruddell, Director of the FEWSION research at Northern Arizona University.

For food and other critical supplies like energy, water or medical supplies to get to us from the places they're produced – these commodities have to flow along complex supply chains, which are critical to our security. That's why it's important to know how resilient these supply chains are to shocks. The notion that your food should come from close to your home, its true from the stand point of community and social connection. Its fresher food and it also reduces transportation costs and greenhouse gas emissions. But what about the case where your local food supply is disrupted by extreme weather events or geopolitical upheavals … or a public health crisis like we had in 2020/2021 with covid-19. In that case, you don't necessarily want all your food -or other critical supplies – to be coming from your own neighborhood, because you need help from someone else.

So, in this episode you're going to hear how FEWSION researchers used methods taken from biodiversity to understand how resilient America's food supply chains are – AND … in turn, how to make them more resilient.

These findings are more than just basic science. They provide a working tool and framework that lets city planner and policy makers design more resilient food supply systems.

These findings may be applicable around the world – in other countries and also for other types of supply chains, like medical or energy.

BR: What I learned from classic ecological theory, is that the term biodiversity describes how many species there are in a given area/ecosystem. Typically - the more diverse an ecosystem and its food web is … the more it can adapt to threats and absorb damage that would disturb its natural balance – like a big storm, or an invasive species.

BR: We can represent that diversity using a number - called the 'Shannon Diversity Index' – which ranges from zero to 1. A value near zero means there's very little diversity, not many species, not a very diverse food web. And then the closer the diversity index to a value of '1' or 100% - the more diverse the system is and the more it can adapt.

BR: That ecological diversity score is where FEWSION researcher Michael Gomez, who's a graduate student at Penn State University, started his research …

Michael Gomez: In an ecosystem every species has a function and contributes to how that system works. We were able to translate this biological diversity concept into food supply chain networks. But instead of studying ecosystems of plants and animals – we studied the human equivalent – cities and their food supplies. Yeah believe it or not – this works!

MG: So, every city has a network of food suppliers that are located near and far away from a city - farmers, food manufacturers, and others. And these food suppliers are located In both cities and rural area – and we shouldn't forget food storage and distribution warehouses. These food suppliers- which are also called trading partners - have diverse characteristics – like the climate they're in, their size and how many people live there or how far away they are. What we were very

interested in was measuring how different the trading partners of a city are using our diversity metric.

BR: Now … the network of suppliers is different for each food product – so to conduct the analysis the team had to group food into categories. They chose FOUR important food groups: crops, live animals, animal feed and meat products. The data came from a system called the Freight Analysis Framework – which has SIX agricultural categories, says Michael Gomez ...

MG: We didn't use fruits and vegetables because they are mainly imported to the US and we were just looking at domestic supply – and milled grains are more like more processed food. And what we have here these 4 categories – are more raw products. Then, we calculated the diversity of each US city's suppliers in terms of.

- geographic location they're in
- the level of economic specialization of the trading partner, this is if its agricultural or industrial
- also the level of urbanization
- we also had the climate that these trading partners or food suppliers are in – and for this we used the Palmer Drought Severity Index
- and finally, we had a modularity network metric that was useful to us to see what trade community these trading partners belonged to.

BR: Michael used these indicators to calculate the food supply chain diversity index…

MG: I think this diversity metric is best explained with an example. Let's say a city obtains 90% of its total food demand from trading partners that are all within the same geographic location and climatic region and the other 10% from trading partners elsewhere. In this example, if an extreme event – like a flood or a drought – in the area where that 90% of the food supply comes from then that city is more likely to experience a food supply disruption as a result of that extreme event. Whereas another city with a diverse food supply is more likely to resist the impact of extreme events due to the diversity in their supply chain.

BR: With the available data Michael was able to quantify the diversity of the food supply chain for *every* city in America... BUT…

MG: … not every American lives in a city. So we also considered areas that are not cities – and we grouped all these areas that are not cities and called them 'remainders of state'.

BR: The remainders of the state are rural areas, right? So, dividing up the data in this way gives a total of 284 cities and 45 rural areas that are the 'rest of the states' across the US.

This work took a MASSIVE amount of data and one of the biggest challenges was to bring it all together, to fuse that data all at the same scale.

MG: It was a bit difficult at the beginning – once when I worked with the data more and more it became easier.

BR: In fact, an analysis like this has never been done once before – and only for one city – that was Flagstaff, Arizona. Never for all cities across the US> So… it's really quite ground breaking.

MG: To do this for the entire US I needed a big computer! Luckily I got to work with the Penn State University supercomputer. At the beginning it was a bit challenging to use this supercomputer

because it's a different operating system – LINUX – that I wasn't used to working with. But at the end the advantages of using this computer overcame all of the initial difficulties of working with the computer. Some of my calculations were really huge. In fact one sensitivity analysis we did in this study took a two whole days to run in the Penn State supercomputer – that's quite a long time for a supercomputer!

Alfonso Mejia: We engineers are pretty good at managing and planning around and predicting for *specific* risks –

I'm Alfonso Mejia Associate Professor in the Department of Civil and Environmental Engineering at Pennsylvania State University… I'm Michael's supervisor and a member of the FEWSION research team.

So for this study we used ecological diversity to develop a relationship between the frequency of supply chain shock and the diversity of a city's supply chain. But what we wanted to do here was to model resilience to ***any*** type of hazard – and we wanted to do this to cope with unexpected disruptions to the food supply chain and improve our ability to cope with those types of disruptions, now and in the future.

Analyses of food supply systems and food supply shocks are typically done on the production side of things – for instance how can we grown different type of crops to make production more resilient to climate, or pest or other disruptions. But this tends to leave cities out of the picture and that's where most people live, and where most of the food gets processed and consumed.

BR: In order for cities and the people that make them tick to be more proactive in building resilience against food shocks, Mike's approach provides a way for cities to quantify their supply chain diversity and potentially to come up with new strategies to increase that diversity if they need to.

BR: Coming back to what I said at the beginning - Mike tested the hypothesis that a city's supply chain acts a lot like an ecosystem's food web… and excitingly he found out that the ecological theory fits a city's supply chains pretty well!"

Food supply chain diversity means that a city is connected to regions with different characteristics – regions in different climates, ecosystems, demographics. A food shock means that a city receives less food because agricultural production decreases somewhere in the system – in this case we're talking about the US food system.

BR: Besides finding the relationship between supply chain diversity and food shock intensity, Michael Gomez also used this method to develop a risk model. That model is similar to how engineers design city infrastructure to withstand flooding and other natural disasters... Its also the sort of model that insurance agents and statisticians rely on.

AM: So, that's an advantage - the risk model is already familiar to planners, insurers, and engineers. The model allows a city to decide a level of resilience against food shocks and determine how diverse the supply chain needs to be to meet that level of resilience. This I think provides an important initial step in designing policies that achieve supply chain resilience. Once a city knows it needs to increase diversity, that city could then start working with partners, companies, and individuals on ways to foster diversity and meet supply chain resilience goals.

BR: Previous studies on food shocks were done on one side of the equation – either supply OR demand. But this study, covers shocks coming from both sides of the trade – supply AND demand.

MG: So, we did this because first – we were interested in analyzing cities which at least in the US they don't' produce the food they consume, the food that they consume is produced elsewhere – in rural areas. And also, in the US we have different areas that are specialized in the production of a particular commodity, like corn production in the corn belt located in the Midwest and also cattle production in the Southern Great Plains.

BR: The next step was to measure the effect of a shock or disruption to the food supply. To do this, Michael came up with a method based on probabilities….

MG: So what we did is we calculated the probability of a city's food supply system to be shocked. And I came up with a way to measure how resilient a city is when it experiences a shock. Human food supply chains are much like natural ecosystems. Their resilience to shocks is made up of three things starting with 'R' – which are resistance, robustness and recovery.

MG: What I did was to measure the annual inflow of domestic food grouped as - crops, live animals, feed, and meat - into each city in the US between 2012 and 2015. This period is a good period to study in in the US because during this period there was a large drought that affected agricultural production across the Great Plains and the western United States.

BR: THEN they had to define what a shock was …

MG: What we called a shock was when the food inflows to a city dropped by more than 3% to 15% in any given year. Using thousands of food inflow data for hundreds of cities across the US, I calculated the probability of exceeding a level of shock for a year for every city. A city with a higher resistance to food supply shocks has a low probability of experiencing a shock.

BR: You might remember from the introduction, that this diversity of a city's food supply is expressed with a single number – the 'Shannon Diversity Index', which after all this work is what the Penn State supercomputer spat out – to Michael's great excitement…

MG: When the results finally started tumbling out of the Penn State supercomputer, I was very excited. Because my main finding was that, just like in many natural ecosystems, diversity in the supply chain REALLY DOES help cities to reduce their likelihood of experiencing a disruption to their food supply. And it doesn't seem to matter WHAT KIND OF SHOCK that is or whether we can see it coming – basically supply chain diversity is good all round!

MG: We were not expecting to get his result. The theory is there – but this theory is for ecological systems, so we weren't expecting to see this as clear as we saw this, with such a significant and strong relationship between the diversity and the probability of shocks. After plotting this relationship - I got excited first at watching what we found – so I immediately sent an email to Alfonso to let him know that I found something and that we should meet in his office. And then I showed it to him and he was also very happy to see that result.

BR: So, what this all means is that … mostly across the US there are very FEW places with low food supply chain diversity. US communities have diversity scores mostly around 67% or higher – and this is great news. It that means that the country's food supplies have reasonably resilient food supplies that are resilient to shocks.

The scores across the US vary quite a bit by region – we found that regions in the West are less diverse than regions in the East – which was kind of expected because in the East we have more food suppliers and trading partners which makes it easy for cities in the East to trade with more diverse trading partners.

AM: So to me I think the most exciting part is that I feel that we were able to come up with a way to deal with or potentially deal with food supply shocks. It is now obvious that we have the result. But when we started this research it was not obvious that diversity was going to be helpful for supply chains – there were indications, perhaps suggestions that this was going to be a good way to go about it, but it was only after we performed the analysis that it became clear that this was a useful way of understanding disruption and resilience to those supply chain disruptions in food systems.

So when we got our final result it was a relief to see that we could explain with a simple relationship resilience and shocks to food systems and cities.

I should just explain here that food supply across the US is organized into geographic regions – different than states or river basins. They have their own geographic regions. So most domestic food production tends to travel within these regions. So most of the time food production doesn't' travel across regions, it stays with these regions and its consumed within the same region. These regions are the main trunk of Mississippi, the North West US, the North East US, and most of the South West. And then there is Texas, which is its own region. Just like it's electrical power supply situation, Texas likes to be independent in terms of where it gets most of its domestic food supply from.

BR: But that self-sufficiency means that cities in the Lone Star state are potentially at more risk of a shock to their supply chains, than more connected cities in neighboring states. And there's one more finding from this that Alfonso Mejia thinks is *particularly* important…

AM: If you look at the data on food insecurity, on average its 10-12% of total population – which is a level for developed countries. So if you look at countries in western Europe they have a similar level of food insecurity. So in that sense the US is doing fine not different from other developed countries. BUT … when you break down that data into geographic regions and different demographics, food insecurity can be two to four times higher – maybe 20, 30 or even 40% of population in the US for in some cities, maybe rural communities … especially in states like Alabama and Mississippi. And if you combine that with where you have more frequent food supply disruptions – you're also starting to get food prices that are more volatile, and food-related businesses have trouble staying in business. For low-income groups even small changes in food prices can have big consequences in their ability to afford adequate food. And its Blacks, Hispanics, Native Americans, along with single mothers - that suffer most from food insecurity during times when there are shocks to the food supply chain.

BR: This was NOT what Alfonso had been expecting…

Yeah I was surprised that this was the case. So this is USDA data and its been available for decades already and the results are very clear. You see a spiking in 2008 2009, when we had a financial crisis, you saw it going up, food insecurity for these marginalized groups goes up a lot – even levels you see in extreme cases like in Africa. We're in a developed country so its shocking to see this happening here.

AM: So the hope is that the tools we are providing will help cites start doing something about food shocks and making their food supply chain more resilient. And we think that one of the most

immediate consequences of that will be potentially to help these marginalized groups that are impacted the most by these disruptions.

MG: What this study clearly shows is that it's not beneficial for a city to be trading with other areas with the same physical, social and economic charactistics. Now… I'd really like to take this approach to other countries – to see if the same principles as in the US works there.

BR: You can read this study in a new article in the journal *Nature*, and you can find maps of supply chain resilience for your community on the FEWSION website. Those maps cover food supply chain resilience, but also the resilience of your pharmaceuticals, electricity, fuel etc.

These findings reveal that having a variety of suppliers in lots of different places using range of modes of transportation is more resilient and adaptable to all kinds of shocks, no matter what they were caused by.

Could be a drought, a pandemic or a hurricane, a volcanic explosion, an oil embargo … OR maybe something we never saw coming – a 'Black Swan'.

All-hazards resilience is true resilience.

Narrator: The NEXT big challenge is to discover HOW cities, countries, and companies can achieve those diversely sourced supplies *WITHOUT* incurring significant increases in cost or making sustainability worse by increasing greenhouse gas emissions!

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