Food System Resilience Indicators for Hawai'i

Rachel Mason, December 2023

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Summary

This report presents a preliminary set of food system resilience indicators for Hawai'i. These indicators are expected to be correlated with the ability of the food import and distribution infrastructure on O'ahu to maintain food availability during and after a hurricane, and for food to remain physically and economically accessible to island residents. The indicators were derived from existing knowledge about vulnerabilities and gaps in Hawai'i's food system. Each one can therefore be traced back to a specific observation about the system. The report also discusses the considerations and challenges involved in defining indicators of food system resilience, and briefly reviews the strengths and shortcomings of previous work in this area.

Hawai'i's food system

Hawai'i's food system has some clear vulnerabilities. Most of the state's food is imported from overseas; only about 12% originates in the islands. The vast majority of these imports arrive through Honolulu Harbor, with a small amount via air freight and a handful of secondary ports. These ports of entry, as well as the main food distribution facilities, are in locations that are vulnerable to inundation by a major tsunami or hurricane. An event that caused a loss of power, from a hurricane to a cyberattack, could also close the ports. Food businesses operate on a 'just-in-time' inventory model, the state and counties do not stockpile food, and FEMA and the military are prepared to feed just a small fraction of the population for a short time.

In addition to these vulnerabilities in the imported food supply chain, Hawai'i's food system is at risk from a variety of other disruptions. Local events such as volcanic eruptions, floods, and fires can impact access to food via their physical and economic consequences. Global-scale and longer-term stressors can also affect Hawai'i's food system. For example, while imports largely continued during the COVID-19 pandemic (thanks to concerted efforts by many actors), widespread unemployment meant that many people became unable to afford food. This in turn points to deeper problems with the food system and the economic and social structures that underpin it - even in 'normal' times, Hawai'i's food system leaves many people in the islands without access to sufficient, affordable, and acceptable food, while an economic downturn may tip many others into food insecurity.

It should be possible to use tools and approaches from the fields of disaster preparedness and resilience to improve this situation. Researchers and practitioners in these areas have developed methods to identify threats, vulnerabilities, and strengths in food systems, and to create strategies to improve a system's ability to function during and after a disruption. Indeed, much work has been done to uncover assets, gaps, and weaknesses in Hawai'i's own food system, to prepare for shocks, and to make improvements (e.g. HI-EMA 2018, Miles 2020, Shaw et al. 2021, Kokubun et al. 2022). It would now be beneficial to track progress towards a more resilient state, showing whether failure points and vulnerabilities are being addressed, and whether interventions are moving the system in the right direction. However, at the time of writing there is no widely-applicable and generally-accepted methodology for creating indicators of food system resilience.

As a step towards defining food system resilience indicators for Hawai'i, this report first examines some of the considerations involved in establishing such indicators. We then review some case studies in which food system resilience indicators have been created and used. Based on this information, and having concluded that existing methods are not directly applicable in the current context, we develop a methodology for deriving indicators of resilience in Hawai'i's food system. Importantly, these indicators are *traceable*, meaning that each one can be followed back to a specific observation about the system.

The derived indicators address only one domain of the food system, and a single threat. Still, we anticipate that this work will contribute to food system resilience scholarship by clarifying the challenges involved in defining indicators and illustrating a potential path forward. This report also contributes to work on Hawai'i's food system itself by defining a set of preliminary, but informative, indicators of resilience.

Food system resilience indicators: considerations and challenges

Food system resilience has been conceptualized in many different ways (van Wassenaer et al. 2021, van der Lee et al. 2022, Roosevelt et al. 2023). Here we adopt the definition of Tendall et al. (2015): Food system resilience is the "capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances." Resilience means that a system loses less functionality during a disturbance, more quickly returns to good functioning, and is better able to learn, adapt, and transform.

The resilience of a food system is most commonly judged by creating a narrative assessment. Here, techniques such as expert interviews, reviews of existing documents, and various types of mapping are used to produce a qualitative assessment of resilience and identify possibilities for improvement (Himanen et al. 2016, Zeuli & Nijhuis 2017, Biehl et al. 2018, Shaw et al. 2021). To give just one example, Biehl et al. (2018) used the above tools to assess vulnerability and preparedness in the city of Baltimore's food system, and provided policy recommendations aimed at increasing resilience. The experience of Baltimore and other jurisdictions has since been used to produce a food system resilience planning guide for local governments (Moore et al. 2022).

We now wish to extend beyond these qualitative judgments, and create quantitative indicators of resilience. Indicators are measurable items that can provide insights into the state or performance of a system. They are used to track changes, assess progress, or signal potential issues within a system, and are intended to concisely communicate information that enables stakeholders to make informed decisions and take appropriate actions. As resilience itself cannot be directly measured, resilience indicators are proxies or surrogates that we can reasonably expect to be strongly and positively correlated with desirable food system outcomes (Darnhofer et al. 2010).

At the level of the food system (as opposed to the individual, household or community level), resilience indicators and methods for defining them are not yet well-developed. According to Biehl et al. (2018), "the field has not yet coalesced around established indicators to measure food system resilience". A handful of studies that have made progress in this area will be reviewed in the following section. However, as Moore et al. (2022) note, "Further work is needed to develop approaches to and specific data sources for measuring [food system resilience] attributes".

One reason why this task is difficult is that a food system is a complex system. It has units that operate on various scales (e.g. household, regional) and involves many actors (e.g. farmers, policymakers), domains (e.g. economic, social, ecological), and subsystems (e.g. import supply chain, farm-scale nutrient cycling). It is not immediately obvious which parts of the system are essential to keep track of, nor which measurements would be a good reflection of them. For example, as we discuss below, various lists of attributes that are thought to confer resilience have been produced, and 'diversity' is commonly among them. It is therefore probably important to 'measure diversity' within a food system, but that could mean counting the variety of funding sources for food banks, crops grown by local farmers, or food transportation modalities, among numerous other possibilities.

Several additional issues arise when attempting to define resilience indicators. For one, a potential indicator could be ambiguous or context-dependent. If the fraction of the population claiming government assistance increases, does that imply that access to programs has improved, or that the gap between incomes and food prices has widened? A large number of engaged and committed food bank volunteers probably contributes to resilience in some ways, but may also impose burdens on certain populations that detract from resilience. Behaviors that may be positive in the face of a hurricane could be negative in a pandemic. Indicators may also be overlapping or redundant. If everyone had the recommended 14-day supply of emergency food at home, indicators of a functioning food supply chain during a disturbance would become less important.

Designing indicators will involve making decisions about the appropriate level of detail or granularity. For example, restrictive contract arrangements meant that school buses could not be used to take food to people during the COVID-19 pandemic in Hawai'i (Shaw et al. 2021). The flexibility of such contracts is likely related to resilience, but should it be explicitly tracked? (And if so, what metric would be used?) Overly detailed indicators could inadvertently function as prescriptions about what should be done.

Finally, measuring and validating indicators requires data and resources. Indicators are intended to be routinely and repeatedly measured, so data availability will likely constrain which indicators are useful in practice. Indicators are also intended to be positively correlated with food system outcomes, so they can in principle be validated using quantitative and qualitative data gathered during past and future disturbances (Tendall et al. 2015). When defining indicators, the feasibility of, and methods for, obtaining and analyzing these data should be considered.

Complex system modeling may be able to resolve some of these issues. Such models are valuable tools that have been used to explore responses to food system disturbances and the effects of interventions aimed at increasing resilience (Candy et al. 2015, Herrera de Leon & Kopainsky 2019). By identifying key factors that increase resilience, complex system models could be used to search for useful resilience indicators. However, these methods still involve subjective choices about model structure and parameters, require data for calibration and validation, and jurisdictions may lack the capacity for such in-depth modeling. No tool is perfect, and indicators potentially offer simplicity and ease of communication. We therefore now review how others have gone about creating resilience indicators at the food system level.

Resilience indicators in the literature

The food systems resilience literature contains discussions of frameworks and concepts, qualitative food system assessments, and methods for estimating resilience at the household or community level. However, there are very few publications that describe something akin to the creation of resilience indicators at the food system level. For the purpose of this report, the most relevant[1] of these are Worstell & Green (2017), Green, Worstell & Canarios (2017), and Jacobi et al. (2018). These studies begin by identifying sets of broad characteristics that are believed to confer food system resilience, which they then convert into specific, measurable indicators.

Worstell & Green (2017) analyzed nine local food systems in three southern US states. These food systems, consisting of farmer co-ops, networks, marketing associations, etc., were assumed to be resilient by virtue of having persisted for several years in states where such food systems are rare. Worstell & Green concluded from these case studies that resilient food systems possess or perform connectivity, local self-organization, innovation, maintenance, accumulation, transformation, ecological integrity, and diversity.

These broad attributes are not directly measurable in themselves, so Green, Worstell & Canarios (2017) searched for routinely-measured, county-level data that could be used to quantify each characteristic. For example, the percentage of farms with internet access was used as the measure of connectivity. The indicators of ecological integrity were levels of chemical inputs, the percentage of organic farms, and the percentage of livestock farms practicing management-intensive grazing.

The indicators were combined into a composite ‘Sustainability/Resilience Index’ (SRI), which was calculated for counties in 13 southern US states. As a first step towards validation, the authors investigated the degree of correlation between the SRI and various development indicators. They found it to be positively correlated with the percentage of families above the poverty line, but negatively correlated with a measure of social capital.

[1] Toth et al. (2016) proposed to “measure resilience” in food systems such as a community garden and an urban farm. They did this by (1) representing the food systems as nodes and links in a network, (2) making a subjective assessment of the resilience of each node and link, and (3) combining node and link resilience to create a single resilience metric. It is not clear how this method would be applied to create resilience indicators for a statewide food system.

Jacobi et al. (2018) started with three ‘core dimensions’ of resilience: buffer capacity, self-organization, and capacity for learning and adaptation (Carpenter et al. 2001). For each dimension, they derived several ‘indicators’. These were largely based on a framework created by Cabell & Oelofse (2012), and included items such as ’natural capital’, ‘decentralization and independence’, and ‘reflective and shared learning’. The Jacobi et al. definition of an indicator differs from the one used in this report: we use the word to denote measurable items, while Jacobi et al.’s indicators are not directly measurable, and their measurable items are referred to as ‘factors’.

Jacobi et al.’s factors are numerous and varied, ranging from from the maintenance of heirloom seeds to the organization of actors in interest groups. They emerged from in-depth study of four food systems: industrial soybean production and an agroecological system in Bolivia, and export-oriented horticulture and a local food system in Kenya. The methods used were participatory food system mapping and interviews, a livelihood survey, an agrobiodiversity study, and participant observation. The resulting measurements, converted to an ordinal scale, were used to compare the resilience of the four food systems across the three core dimensions and their associated ‘indicators’.

The amount of knowledge gathered by Jacobi et al. (2018) is impressive, and it allowed the authors to both quantify resilience attributes and produce an in-depth narrative analysis. Although they did not focus on any specific threat or vulnerability, it seems likely that this type of extensive study would have uncovered issues like those faced by Hawai’i, had they existed, and that this would have been taken into account in the values assigned to the resilience indicators. However, while Jacobi et al.’s work suggests a *method* for defining indicators, it does not supply a blueprint or a set of measurables that can be simply applied in a new setting. Their resource-intensive approach may not be feasible in all locations, readily scaled to larger food systems like that of Hawai’i, or amenable to regular repetition.

In contrast, Green, Worstell & Canarios intentionally restricted their indicators to only readily-accessible data, so they could probably be replicated in Hawai’i. However, the set of indicators they chose has not yet been validated. Moreover, their measured items relate mainly to farm and farmer characteristics. This means that none of them would address the major vulnerabilities of Hawai’i’s food system - there are no indicators that would signal the ability of the food distribution infrastructure to continue functioning if a tsunami hit O’ahu, for example.

Here, then, we explore a different approach. Rather than attempting to derive indicators from broad resilience attributes (which we term a ‘top down’ approach), instead we begin by noting specific gaps and vulnerabilities in Hawai’i’s food system (a ‘bottom up’ approach). We then construct indicators based on these. We aim for a systematic and repeatable process that leads to a set of traceable indicators, in which each item can be followed back to a particular food system issue.

Deriving resilience indicators for Hawai'i

We begin by clarifying the scope of the problem, answering four questions posed by Carpenter et al. (2001) and emphasized by Moore et al. (2022): resilience *of what, to what, for what purpose*, and *for whom*? This narrows down the scales, domains, actors, etc. of the food system that need to be considered. However, it does not lead directly to resilience indicators. We achieve that next step by examining how food is made available and accessible by the food subsystem defined by the four questions, together with existing knowledge about vulnerabilities in that process. This approach is inspired by (but distinct from) the Fault Tree Analysis developed by Chodur et al. (2018). We then supplement the indicators resulting from this 'supply chain perspective' with another set derived from a recent narrative assessment of vulnerability and resilience in Hawai'i's food system. To keep the analysis coherent, we require that all indicators fall within the system boundaries defined at the beginning of the process.

Defining the system

These four questions define the scope of the problem:

Resilience of what? The food importation and distribution mechanisms on the island of O'ahu (i.e., the City & County of Honolulu), from port of entry to household. This infrastructure has been repeatedly identified by local experts as a point of particular vulnerability, with several potential points of failure (Robertson 2015; HI-EMA 2018; Shaw et al. 2021). For simplicity as we develop the methodology, we restrict the analysis to one island/county in the state.

This focus limits the food system actors and domains that will be considered relevant. In particular, it largely excludes the food system based on local agricultural production. We recognize that local agriculture is valuable in many ways, and likely contributes to food system resilience by building social capital, supplying economic diversity, adding redundancy in the food supply, etc. However, in-state food production currently accounts for only around 12% of the islands' needs (Loke & Leung 2013). It is also vulnerable to disruption during extreme weather events (D. Lopez, pers. comm). At least in the near term, local agriculture will not feed all residents during an emergency. While our indicators will include the amount of food produced locally, we consider indicators of resilience *within* the local food system to be outside the scope of this work. Instead, we concentrate on deriving indicators of the likelihood and impact of a disruption to the supply of food brought in from overseas.

Resilience to what? A hurricane that is capable of damaging the food importation and distribution infrastructure on O'ahu. Hurricanes have affected Hawai'i in the past, and the incidence of tropical cyclones passing close to Hawai'i is projected to increase as the climate changes (Murakami et al. 2013). A hurricane in the vicinity of O'ahu would be capable of damaging a wide range of infrastructure via heavy rainfall, storm surge, and high winds (HI-EMA 2018b). Again, for this preliminary analysis we consider only a single type of disturbance.

Resilience for what purpose? Maintaining food security on O'ahu, during and after a hurricane. As defined by the Food and Agriculture Organization of the United Nations (FAO), food security exists when "all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 1996).

The FAO decomposes food security into four "pillars": availability, accessibility, and utilization of food, plus the stability of the food supply. We focus on the first two pillars of food security: availability and accessibility (Figure 1). In selecting resilience indicators, we are effectively searching for predictors of the continued availability and accessibility of food. Maintaining availability implies that sufficient food exists on the island; maintaining accessibility means that the food is affordable and can be physically reached.

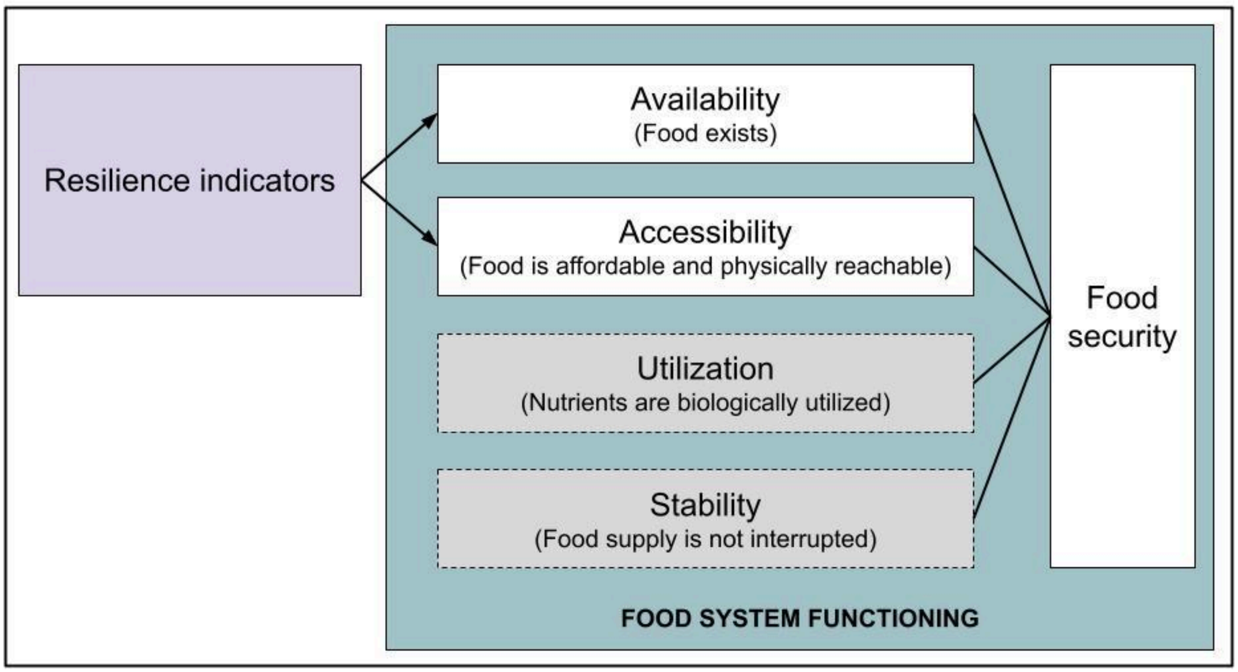

Figure 1. We aim to define resilience indicators that are positively correlated with two pillars of food security: availability and accessibility.

Resilience for whom? All of the ~1 million residents of O'ahu (for simplicity, we neglect visitors). Food security applies to "all people, at all times", implying that the goal of resilience includes maintaining food availability and accessibility for populations that are currently oppressed, marginalized, and/or food insecure. However, we acknowledge that this definition of resilience, and this preliminary analysis, does not touch on deeper issues of equity, sovereignty or justice in the food system.

The supply chain perspective

Figure 2 shows a simplified schematic of the food supply chain on O'ahu. Most food enters the island through one of its ports of entry, and is then transported to one of a number of warehouses and distribution centers. There, items are sorted for delivery to retail outlets, institutions, food banks, restaurants, etc. Locally-produced food also enters the supply chain via distributors, local food hubs, retail outlets, etc., as well as direct sales to consumers. When food is economically and physically accessible to community members, it is transported to homes for consumption and storage. (In the interest of clarity, Figure 2 neglects many details such as the existence of local food processors, and the fact that food is also consumed in restaurants and institutions.)

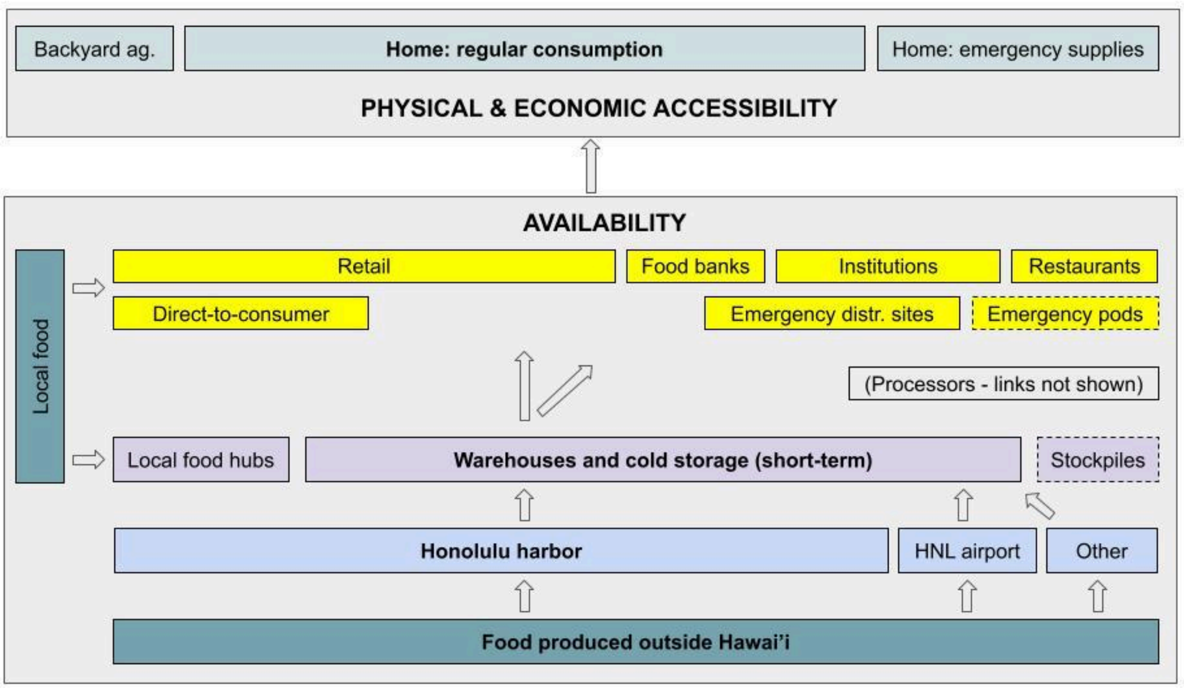

Figure 2. Simplified schematic of the food supply chain on O'ahu. Bold font indicates facilities or points in the chain that dominate a particular stage. Dashed boxes denote supply chain elements that do not yet exist, or exist at a very low level. Colors: Production, Importation, Distribution, Places where people can obtain food, and Household food stocks.

Availability indicators

Previous work has revealed several important facts about the food supply chain. First, almost 90% of Hawai'i's food is imported (Loke & Leung 2013). Honolulu Harbor is the single main point of entry for food and numerous other critical supplies (HI-EMA 2018a). Alternative ports exist (such as Honolulu International Airport and a handful of other harbors), but they lack the infrastructure and/or capacity to provide substantial redundancy. They are also in the same general location as Honolulu Harbor and are therefore exposed to similar threats. At the next step in the supply chain, several food distribution facilities exist, potentially providing a degree of redundancy. However, most are in locations that are at risk from inundation during a hurricane (C. Buck, pers. comm.).

The supply chain operates using an on-demand model. Food shipments arrive every 5-8 days and are quickly distributed to the market; after 5 days, supplies are reduced to around 40% of market capacity

(HI-EMA 2018a). The private sector does not hold any long-term food supplies, and neither do the state or county. FEMA will arrange shipments of ‘push’ supplies in advance of a hurricane, but planning documents state that Hawai’i will be provided with one day’s worth of food and water for 10% of the population (HI-EMA & FEMA 2015). At the household level, a recent survey showed that only 29% of households have the recommended 14 days’ worth of food and water in reserve (Zougris & Miles 2023).

We use this knowledge to derive an initial set of resilience indicators related to food availability (Table 1). Increasing local food production, especially of staple crops, would make it less critical to maintain a continuous stream of imports. The same applies to maintenance of food stockpiles by government entities, non-profits, households, and the private sector. The set of indicators therefore includes the percentage of food that is produced locally, the percentage of households with emergency food supplies, and the person-days of food stored by government, non-profits, and the private sector. Continuity of food importation and distribution would be aided by the existence of backup ports of entry, and distribution facilities that are not vulnerable to inundation. This leads to indicators describing the number of ports that can handle a certain fraction of the total weekly food requirement, and the percentage of weekly food requirements that can be distributed via facilities that are not in the likely inundation zone.

Consideration	Derived Indicator	Label	Notes
Availability: High-level supply chain overview			
Vast majority of food is imported	% of food produced locally	A1	
Most imports enter through Honolulu Harbor	Number of entry ports able to handle >20% of total weekly food requirement	A2	20% is an initial estimate
Many food distribution facilities are vulnerable to inundation	% of weekly food requirement that can be handled by facilities not vulnerable to inundation	A3	
There is little long-term food storage in the state	Person-days of food in locations not vulnerable to inundation, relative to target quantity: private sector, non-profits, government	A4.1, A4.2, A4.3	Separate indicators for different sectors as diversity in stockpiles seems valuable
Few households have emergency food supplies	% of households with recommended emergency food supplies	A5.1	
	% of households likely to experience food insecurity during the disturbance that are served by emergency food pods	A5.2	Food pods are shipping containers pre-stocked with non-perishable foods

Availability: Facilities and transportation links			
Vulnerabilities are known and can be addressed	% known, *major* vulnerabilities that have been addressed	A6	To recognise improvements such as the new Kapalama container terminal
Emergency planning can reduce downtime	% food system businesses, agencies, and facilities with emergency plans	A7.1	"Business, agencies, and facilities" needs to be defined, and should include critical non-food infrastructure
	% plans tested by drills or tabletop exercises in the last 2 years	A7.2	Proxy for quality of plans, ability to execute, working relationships, etc.
	% staff that have experienced similar emergencies in the past	A7.3	Identified as helpful by Biehl et al. (2017)
	% food businesses etc. with emergency food and water supplies for staff	A7.4	See comment for A7.1
Accessibility			
Pre-event food system functioning influences resilience	Monthly income (including government assistance) vs USDA monthly cost of food for the lowest 20% of incomes	B1.1	Averaged over some pre-event time period. See also A5.1, A5.2
	% population that is food secure	B1.2	
	% population that does not live in a food desert	B1.3	
People without vehicle access need to get (to) food	% emergency plans that consider public transit and people with mobility issues	B2	
Population needs information about access to food in emergency	% population with a cellphone	B3.1	
	% emergency plans that include a communications strategy	B3.2	
Other known gaps and vulnerabilities			
More collaboration, coordination, and system-wide strategies are needed	Maintenance, strengthening, and addition of connections between food system actors	C1.1	Could be based on social network analysis performed by Lincoln et al.

	Number of food system-related MoUs signed	C1.2	
More food system data are needed	Are food insecurity data collected at least every 6 months using consistent methodology?	C2	
Emergency feeding may rely too heavily on volunteers	% food bank staff that are paid	C3	
Emergency feeding may be inequitable	Geographic uniformity in per-capita food bank spending	C4	

Table 1. Potential resilience indicators. All indicators are defined so as to have a positive relationship with food availability and accessibility

We supplement the high-level overview of the supply chain by considering the requirements of the facilities and transportation links in the Availability box in Figure 2. In order to function, they need:

- Undamaged equipment
    - Cranes, vehicles, buildings, computers, …
- Fuel and/or power
    - Electricity, diesel, …
- Water and sanitation
- Access
    - Facilities not flooded, blocked by debris, or unsafe; usable roads
- Staff
- Information/communications
    - Cellphone service, logistics and inventory management systems, …

In principle, we could examine each of these requirements for individual facilities, and derive numerous and detailed resilience indicators. For instance, one indicator might be whether Honolulu Harbor management is able to evacuate all container ships at least N hours in advance of the onset of hurricane impacts. However, this level of detail and specificity seems excessive for our purposes, and potentially too prescriptive. Instead, we note that existing disaster preparedness documents list known vulnerabilities, and emergency plans should specify actions that need to be taken before, during, and after an event. Table 1 therefore contains indicators of the existence and quality of emergency plans, along with whether known vulnerabilities have been addressed. We use drills and past experience with similar emergencies as proxies for the quality of emergency plans and their likelihood of being successfully executed (Biehl et al. 2017).

Accessibility indicators

Economic accessibility is a function of income (including government assistance) relative to food prices. On the income side of the equation: incomes need to be maintained during the event, and/or government assistance needs to be quick and easy to obtain, and/or food banks need to be able to meet increased demand, and/or people need access to savings and/or credit. If there is a risk of food prices increasing during the event, preventive actions such as price-gouging prohibitions may be possible[2]. Emergency food stocks at home and elsewhere would make economic access less of an issue during a short-term disruption.

It may be possible to define indicators of whether access to government assistance is straightforward, or whether food banks are likely to be able to meet increased demand, etc. However, it is not clear whether it would be feasible to obtain the relevant data. It is well established, though, that the performance of a food system before a disruption affects its performance during the event (Links et al. 2018). This suggests that an indicator of economic accessibility itself, for which data may be more readily available, could be used to indicate resilience. We suggest three such indicators, all defined so as to have a positive relationship with accessibility:

1. Monthly incomes (including government assistance) divided by the USDA monthly cost of food, for the lowest 20% of incomes. Assessing this indicator for a low income tier means that it reflects system functioning for the population that is most likely to experience food insecurity during a system disruption.
2. The percentage of the population that is food secure
3. The percentage of the population that does not live in a food desert. A food desert is a composite concept that incorporates several aspects of both economic and physical food accessibility in a geographic area: Distance to a supermarket, poverty rates, vehicle availability, and healthy food availability.

As for physical accessibility, the continuity of infrastructure, staff, etc. that are needed to maintain physical access to food should be signaled by the planning- and preparedness-related indicators in the previous section (A7.1-A7.4). To assess whether physical accessibility is likely to be maintained *for all*, we add an indicator of whether those plans include public transportation and consideration of those with mobility issues.

Even if food remains economically and physically accessible immediately after a hurricane, people may need information about where and how to obtain it. To signal whether information is likely to be available and propagate effectively, we include indicators for the fraction of the population that owns a cellphone, and the fraction of emergency plans that include a communications strategy. Indicators of the strength of informal communication networks in communities would also be useful, but to the best of our knowledge, such data are not routinely obtained.

More broadly, communities can certainly contribute to their own resilience, and qualities such as social cohesion, capital, and trust have been identified as likely to increase resilience (Links et al. 2018). These qualities can be measured in many ways, and can apply to various different communities, populations, and entities. This returns us to the complex system problem of which scales, domains, actors, and

[2] E.g. https://trackbill.com/bill/hawaii-senate-bill-1599-emergency-management-proclamations-price-gouging-commodities/2341198/

subsystems to include. Despite having drawn system boundaries using the four questions, it is not clear how to systematically derive specific, traceable social cohesion indicators from the food system knowledge at our disposal. For this reason we defer the definition of indicators in this realm to future work.

Additional resilience considerations

Shaw et al. (2021) identified issues related to the resilience of Hawai'i's food system that would not naturally emerge from the supply chain examination above, but which are within the scope of this work as defined by the 'four questions'. These include gaps in the areas of:

- Collaboration, coordination, and system-wide strategies. Shaw et al. (2021) identified a need for more integrated policies, stronger connections between emergency management and emergency feeding professionals, and avoiding redundancy, duplication, and unnecessary competition (such food banks competing for limited food supplies)
- Data, both for better understanding Hawai'i's food system and for applying for needs-based federal funding. Consistent food insecurity data is a particular gap.
- Flexibility. For example, restrictive contracts meant that it was not practical to use school buses to transport food to people during the COVID-19 pandemic.

Other issues included a reliance on volunteers instead of paid staff (volunteers are an asset but also have a high burden placed upon them, which may be an equity issue), and inequities in emergency food distribution (wealthier areas received higher-quality food). At the same time, flexibility, innovations, and improvements were also demonstrated in response to the pandemic. Notable developments included new professional and purchasing arrangements, new infrastructure, improvements to emergency food planning and operations, and increased attention to food system issues in general.

Several potential indicators could capture some of these issues and gaps. A food system social network analysis for Hawai'i has already been performed (Lincoln et al., n.d.); updating the analysis at regular intervals would indicate the degree to which connections and collaborations are being developed, and is perhaps also related to food system innovations and improvements in general. Business leaders who orchestrated emergency food distribution during previous events have stated that formal Memoranda of Understanding (MoUs) between government and the private sector are needed to enable their work (C. Buck, pers. comm.). The number of such MoUs that have been signed is therefore likely to be a good indicator. The routine collection of food security data, the percentage of food bank staff that are paid, and geographic uniformity of per-capita food bank spending also seem like plausible resilience indicators in the specific case of Hawai'i.

Relationship of resilience indicators to resilience attributes

In Table 2, we link the resilience indicators with the broad resilience attributes defined by Moore et al. (2022). This is a very subjective exercise, but some of the results may be informative. In particular, Table 2 shows that we have few indicators of connectivity and flexibility in the food system. This is likely because these attributes are difficult to measure without going to an unwarranted level of detail, or with widely-accessible data. Inflexibility in school bus contracts was identified as a barrier by Shaw et al. (2021), but an indicator such as “are county governments able to use school buses for emergency feeding purposes?” seems too specific and prescriptive. And we probably cannot routinely measure whether, say, staff at food businesses have the flexibility to adapt on-the-fly to changing conditions and needs.

Resilience Attribute	**Indicators**	**Comments**
Diversity	A1, A4.1, A4.2, A4.3	A4 may imply diversity in acquisition, management, and location of food stockpiles.
Redundancy	A1, A2, A3	Local food production probably increases both redundancy and diversity
Connectivity	C1	
Capital Reserves (social, political, financial, natural)	A6, A7.2, C1	Addressing major vulnerabilities and conducting multi-agency drills may increase social and political capital
Flexibility	A2	The ability to switch between ports implies flexibility
Preparedness	A2, A3, A4, A5, A6, A7, C2	
Equity	A5.2, B1, B2, C3, C4	

Table 2. Links between resilience attributes and indicators. Diversity = different ways of achieving the same outcome, redundancy = multiple instances of the same object or process.

Discussion and next steps

We aimed to choose a set of resilience indicators that were well-defined in scope, and derived directly from existing knowledge about threats, vulnerabilities, gaps, and assets in Hawai’i’s food system. This results in a set of 24 traceable indicators with transparent origins. The indicators address all of the resilience attributes listed by Moore et al. (2022), although some are better-represented than others. The process was intended to be as systematic as possible, but subjective choices inevitably needed to be made. Many of these related to the level of detail and specificity at which to operate.

The preliminary set of indicators should now be adjusted and strengthened in several ways. First, review by food system and emergency preparedness experts may correct any flaws in the food system model and assumptions that were made in this work, leading to more relevant and helpful indicators. Experts' experience with past events, such as the tragic August 2023 Maui fires, may also shed light on whether these indicators would provide useful information in practice. The relevance of the indicators will probably change over time, so reconvening at regular intervals would be helpful.

Second, data availability needs to be more thoroughly assessed. Some potential indicators were already rejected due to the likelihood that suitable data would not exist, but it is possible that even some ostensibly straightforward or common measurements (e.g. local food production, food security rates) are in fact quite complex to obtain. Note that indicator B1.2 in Table 1 assumes that food security data are regularly collected, while indicator C2 asks whether this is in fact the case.

On a related note, most indicators will need more detailed definitions in order to be made measurable. For example, to assess "% of households likely to experience food insecurity during the disturbance that are served by emergency food pods", the definition of a "household likely to experience food insecurity" needs to be established. The same goes for 'weekly food requirement', 'vulnerable to inundation', and several other terms used in Table 1.

A few questions remain to be answered:

- How can/should these indicators be verified or validated?
    - What data are needed and available?
    - What combination of statistical techniques, expert opinion, and/or simulation should be applied?
- Should the indicators be weighted or prioritized?
    - Adding more emergency food pods plus modest upgrades to secondary ports could contribute significantly to resilience (D. Lopez, pers. comm.). How should/could that type of information be incorporated?
- How can indicators of resilience in other food subsystems, and indicators of 'general resilience' (Carpenter et al. 2012) be added in a systematic, transparent, and practical way?

Rigorously defining effective indicators of food system resilience, and consistently monitoring them, is a significant challenge. Nonetheless, such indicators promise to increase the visibility of vulnerabilities in Hawai'i's food system, and demonstrate progress towards a more resilient state. We hope that this preliminary work will set the foundation for an ongoing monitoring and evaluation framework, alongside the development of system-wide food policies that will help Hawai'i to thrive in the face of future challenges.

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