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# Building the resilience of agri-food systems to compounding shocks and stresses: A case study from Melbourne, Australia

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**Introduction:** The war in Ukraine is causing significant disruption to global agri-food systems, which are still recovering from the effects of the COVID-19 pandemic. In Australia, these global shocks followed a series of localized climate-induced crises from forest fires, floods and drought. There is a pressing need to increase our understanding of ways to strengthen the resilience of agri-food systems to multiple shocks and stresses that co-occur or follow on each other. The aims of this study in Melbourne, Australia, were to investigate how forest fire and pandemic shocks affected the agri-food system, to identify vulnerabilities in the system, and to explore opportunities to build resilience to future shocks and stresses.

**Methods:** Semi-structured interviews were conducted during 2020-21 with 41 key stakeholders from government, industry and civil society organizations.

**Results and discussion:** Vulnerabilities identified in agri-food supply chains included geographic and corporate concentration, complex "just in time" supply chains, critical infrastructure and logistics, and workforce availability. Strategies identified to build the resilience of agri-food systems include increasing the diversity of supply chains, decentralization, collaboration throughout agri-food supply chains, and ensuring sustainable livelihoods.

**Conclusion:** Our study highlights the cascading effects of multiple shocks and stresses on agri-food systems, and the need for greater policy focus on transformative actions that build the resilience of agri-food systems to any future shock, and that counter the cumulative effects of underlying environmental stresses.

KEYWORDS

**climate change, pandemic, policy, adaption, transformation**

## 1. Introduction

The war in Ukraine is significantly affecting global agri-food systems, disrupting agricultural production and supply chains, and contributing to the rising cost of fuel, fertilizer and food (FAO, 2022b; Mottaleb et al., 2022). This latest disruption adds to the impacts of the COVID-19 pandemic and climate shocks and stresses on global food systems (Béné et al., 2021; Romanello et al., 2022). Disruption to agri-food systems is driving sharp increases in global food insecurity and hunger (FAO, 2022; von Grebmer et al., 2022).

There is a pressing need to increase our understanding of ways to strengthen the resilience of agri-food systems as climate events, including drought, fire, and flood, are projected to increase in frequency and severity in coming years (IPCC, 2022). Multiple and concurrent shocks are also compounding the impacts of shocks to agri-food systems and the challenges of strengthening their resilience (Quigley et al., 2020). However, relatively little research has been undertaken into the resilience of agri-food systems, and our understanding of what makes agri-food systems resilient is only just emerging (Biehl et al., 2018; Vieira et al., 2018; Hecht et al., 2019; Bene, 2020).

Researchers have called for more empirical evidence about food system resilience that builds on conceptual understanding (Ericksen, 2008; Tendall et al., 2015; Ali et al., 2022). There is also a need for more holistic research that investigates resilience across the whole agri-food system, rather than one part of the system in isolation (James and Friel, 2015; Zurek et al., 2022). However, to build resilience, it is important to understand how agri-food systems are affected by shocks and what that tells us about their vulnerabilities (Quigley et al., 2020; Stephens et al., 2020). It also requires consideration of underlying environmental stresses. The natural resource base that underpins global food production is under pressure from the degradation of land and water systems (Fan et al., 2021a), biodiversity loss (IPBES, 2019), high levels of food waste (UNEP., 2021), and declining availability of agricultural land (Fan et al., 2021a). There are interactions between these long-term environmental stresses and sudden shocks (Zurek et al., 2022), and there is a need for empirical studies of food system resilience that consider both.

This paper aims to address these research gaps by investigating food system resilience to climate and pandemic shocks and stresses in Melbourne, the capital city of Victoria in south-east Australia. Melbourne has a population of around 5 million people (Australian Bureau of Statistics., 2021), and is experiencing rapid growth and urbanization on its peri-urban fringe. Melbourne's city region comprises 31 local government areas in the metropolitan area and another 9 local government areas that form a peri-urban ring around the city (Murphy et al., 2022). The study began during the 2019-2020 Australian "black summer" forest fires. These fires were of unprecedented scale and intensity, burning more than 24 million hectares of land and killing three billion animals, with an estimated financial cost of more than $10 billion (Commonwealth of Australia, 2020). The fires occurred during Australia's hottest and driest year on record, when much of the country was already drought affected (Commonwealth of Australia, 2020). As the fires were receding, the COVID-19 pandemic outbreak started with the first case in Victoria detected in January 2020 (Storen and Corrigan, 2020).

This case study analyzes the effects of multiple shocks and stresses on Melbourne's food system and identifies the features of the food system that contribute to resilience. It highlights the importance of taking actions that strengthen the resilience of food systems to a wide range of potential shocks and that also build the long-term resilience of food systems to ongoing environmental stresses. This paper begins with a review of the literature about the concept of resilience in food systems and it provides an overview of empirical studies that have investigated the resilience of food systems to shocks and stresses.

## 1.1. The concept of resilience in food systems

A food system comprises the actors and activities involved in producing, processing, distributing, retailing, disposing and consumption food, and the interactions within the system (Ericksen, 2008; HLPE, 2017). Tendall et al. (2015) define resilience of a food system as 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" (Tendall et al., 2015). Their food system resilience action cycle emphasizes preventive action to build robustness to withstand a disturbance, and reactive action to absorb the disturbance, act flexibly and recover from the disturbance with resourcefulness and adaptability (Tendall et al., 2015). The concept of resilience emerged from the study of socio-ecological systems and their capacity to absorb a disturbance, to adapt and learn in the face of change (Folke, 2006), and it has only been applied to food systems relatively recently (Béné et al., 2016; Constas et al., 2022).

The United Nations conceptualizes resilience as the ability of systems, institutions and people to prevent, resist, absorb, adapt, respond and recover when confronted with risk (United Nations., 2020). Applying this definition to food and agriculture, the FAO noted that agri-food systems require absorptive, adaptive, anticipating, preventive and transformative capacities to overcome multiple overlapping shocks and stresses, achieve food security for all, and decent livelihoods for actors within the agri-food system (FAO, 2021).

## 1.2. Features of resilient food systems

A number of empirical studies have investigated the resilience of food systems in the context of specific shocks, particularly climate-related events and the COVID-19 pandemic (for example, Smith et al., 2016; Béné et al., 2021). Several studies investigated the resilience of food supply chains in Queensland, Australia, following widespread flooding in 2011 (Smith and Lawrence, 2014; MacMahon et al., 2015; Smith et al., 2016). Other studies have investigated the resilience of foods systems in Christchurch, New Zealand after an earthquake (Berno, 2017); in New York City, USA after a hurricane (Chan et al., 2015); and in northern Bangladesh after flooding (Smith and Frankenberger, 2018).

These empirical studies of climate and pandemic events reveal some features of resilient food systems. Multi-stakeholder coordination across supply chains and strong networks of food system actors promoted resilience during flooding (MacMahon et al., 2015; Smith et al., 2016). Community resilience—the collective capacity to respond—strengthens food security and the resilience of food systems (Smith and Lawrence, 2014; Chan et al., 2015; Berno, 2017; Smith and Frankenberger, 2018). Home gardening, community gardening and urban agriculture play a role in building community resilience and support food security during climate and pandemic shocks to food systems (Chan et al., 2015; Lal, 2020; Niles et al., 2021). Studies of food supply chain resilience during the COVID-19 pandemic in Canada and the US (Hobbs, 2021), and Australia (Snow et al., 2021; Jones et al., 2022) also

showed that strong interpersonal relationships and networks across supply chains strengthen resilience.

Diversity in agri-food systems emerges as a hallmark of resilience. Diversity of crops, suppliers and production methods supported resilience during the Queensland floods, as well as the ability to respond to the shock quickly and flexibly (Smith et al., 2016). Love et al. (2021) found that diversity at the community, company and industry level built the resilience of the global seafood industry during the COVID-19 pandemic. Other studies of food system resilience during the COVID-19 pandemic have also noted the importance of diversity in food supply chains (Bisoffi et al., 2021). Flexibility and adaptability were identified as key to supply chain resilience in both long and short food supply chains (Chenarides et al., 2020; Hobbs, 2021). In the US, local and regional food supply enterprises were able to flexibly switch to new logistics and distribution approaches, including direct to consumer produce boxes and online marketplaces (Thilmany et al., 2020; Marusak et al., 2021).

Other studies have investigated the resilience of city food systems using a vulnerability assessment approach (Blay-Palmer et al., 2018). Vulnerability assessments have been used to identify geographic areas and population cohorts most vulnerable to food insecurity in the event of a shock to the food system (Zeuli et al., 2018). A study in Toronto, Canada assessed the vulnerability of the city's food system to three extreme weather scenarios linked to climate change and found that interdependencies between the food system and other systems, such as transportation and telecommunications, were a key vulnerability (Zeuli et al., 2018). A study in the US city of Baltimore found that preparedness, relationships and communication, diversity, redundancy and post-event learning were key to resilience in a disaster scenario (Hecht et al., 2019). While these studies provide insights into the features of resilient food systems in the face of a single shock, there is a need to understand how food systems are affected by multiple shocks and stresses and the features of food systems that strengthen resilience under these circumstances.

The aims of the present study were to: (i) investigate how the forest fire and pandemic shocks affected Melbourne's food system; (ii) identify food system vulnerabilities to these shocks; and iii) identify features of the agri-food system that strengthen resilience. Our analysis includes a focus on the perceived impacts of shocks and stresses in Melbourne's city region and in other areas of Victoria which are important to the city's food supply.

# 2. Methods

## 2.1. Theoretical approach

The study draws on findings from a three-year research project that was informed by the City Region Food System (CRFS) approach (Carey et al., 2022; Murphy et al., 2022). The CRFS approach focuses on strengthening linkages between cities and their surrounding peri-urban and rural areas to improve the resilience of food systems, and to safeguard food security and livelihoods (Blay-Palmer et al., 2021; FAO, 2022a). The CRFS approach offers potential for conceptualizing more sustainable food systems by engaging multi-sectoral actors from across the food system to identify integrated policy action across the city region (Blay-Palmer et al., 2018). We take an integrated "food systems" approach to examining resilience through food supply chains, recognizing that changes in one part of the food system can have unanticipated consequences in other parts of the system (Ingram, 2011). We distinguish between shocks, which are sudden events that disrupt agri-food systems, and longer-term stresses, which have more gradual impacts (Zurek et al., 2022).

## 2.2. Data collection

We conducted 34 semi-structured interviews with 41 participants from May 2020 to March 2021, to gain an in-depth understanding of participant perspectives on the resilience of Melbourne's food system to shocks and stresses. Semi-structured interviews were considered appropriate as they have a flexible structure that uses open-ended questions to explore a topic, and allows for follow-up questions to probe participant responses (Roulston and Choi, 2018). The interview guide sought to collect data on the perceived impacts of climate and pandemic shocks and stresses on the food system, and opportunities and barriers to strengthening the resilience of Melbourne's food system to future shocks and stresses (Table 1). All interviews were conducted with two members of the research team present (MM, RC, LA), using online communications platforms (Zoom or Microsoft Teams). All interviews were audio-recorded and transcribed. Participants were given the opportunity to review and amend a transcript of their interview.

## 2.3. Sampling and recruitment

We used purposive sampling and snowball sampling to select interview participants from government (local and state), industry and civil society organizations who were engaged in one or more parts of the food system (production, processing, distribution, retailers, consumption, waste). Purposive sampling selects information-rich cases for in-depth study and understanding of the phenomena of interest (Patton, 2002; Liamputtong, 2019). Potential participants were identified through organizations' websites, the authors' networks, and through the professional networking site (www.linkedin.com). Participants were approached by email with a plain language statement and consent form attached. Signed consent forms were obtained prior to interview. Snowball sampling was used at the end of interviews whereby participants were asked to identify others who may be useful to interview. Ethics approval for the study was granted by the University of Melbourne (Ethics ID: 2056495.2).

## 2.4. Participants

There were 41 interview participants from government, industry and civil society organizations. Interviewees had professional roles and responsibilities that focused on each stage of the food system: production, processing, distribution,

TABLE 1 Interview guide.

| | |
|---|---|
| Introduction | Tell us about your interest in the resilience of the food system to climate or pandemic shocks and stresses and any involvement or experience in your current role in issues related to the resilience of the food system to shocks and stresses. |
| Roles | What role does your organization play in the event of a disruption to the food system? What plans does the organization have in place for those events? |
| Impacts | What types of impacts have you seen from climate-related shocks and stresses or pandemic stress on our food system? Who has been most affected by the impacts?<br>What steps were taken to address the impacts and how effective were they? |
| Governance | What is the role of state and federal government and the food industry in managing supply issues relating to COVID-19 or other shocks?<br>What is the governance around building resilience of the food system in the longer term? |
| Policy | What are the policies and strategies that provide direction in the short term? What plans or strategies are in place to build the resilience of the food system in the longer term?<br>What steps do we need to take to increase the resilience of the city's food system to climate shocks and stresses? To pandemic stress? |
| Opportunities and barriers | What are some of the opportunities that could be leveraged to make progress on that? What are the barriers to making progress? How could those barriers be addressed? |
| Preparedness | What are the "other" shocks that you worry about, those that we may not have experienced yet? What are the policies and strategies we need in place to safeguard against future scenarios? |

retail, consumption and waste resources. Four participants had responsibilities that covered the whole food system. The average interview length was 53 min. Table 2 presents the participant characteristics by sector and food system stage.

## 2.5. Analysis

Data were analyzed qualitatively by the researchers (MM, RC, LA) using thematic analysis (Braun and Clarke, 2022). Data were initially assigned into categories by food system node and by shock or stress by the lead author (MM) using open coding and focused coding approaches (Skeat, 2013; Bryman, 2016). Through an iterative process, recurring patterns and themes that emerged from the data were discussed and refined by all authors (MM, RC, LA) during and after the interview period, consistent with a thematic analysis approach (Liamputtong, 2019). The interview guide was revised and tailored during the interview period to interrogate emerging issues. Data were analyzed in NVivo 12 qualitative data analysis software (QSR International).

# 3. Results

## 3.1. Perceived impacts of shocks and stresses across the agri-food system

Participants reported their experiences of the impacts from the forest fires and the COVID-19 pandemic across the agri-food system.

### 3.1.1. Fire

The 2019-2020 forest fires affected the agri-food system in rural and regional areas of Victoria and other states, which influenced food flows into Melbourne. According to participants, immediate effects on agricultural production included loss of livestock and crops in the fires, and smoke-tainting of agricultural produce. Participants reported that smoke haze persisted for weeks after the fires "adding seven to 9 days to their growing season for [vegetable] products" (interview 26, industry), and that there were concerns about the longer-term impacts on agri-food production.

The fires disrupted agri-food distribution and retail in fire-affected areas because roads were blocked by fallen trees or damaged by heat.

> *In the case of the bushfires, the normal food supply trucks literally couldn't get into places like Mallacoota, so we had to work with them to establish alternative supply routes, we had to find alternative ways to supply the supermarkets and shops. - Interview 8, government*

Participants described how some communities were completely isolated for several weeks and how power and telecommunications outages affected retail in fire-affected areas. Participants reported that food relief organizations coordinated the provision of food "for people in all of the fire-affected areas, which included the airdrops of food into isolated communities" (interview 6, civil society). Participants experienced increased food loss and waste due to delays in harvesting fruit and vegetables, and power outages that led to the loss of food stocks in stores and in homes.

### 3.1.2. Pandemic

While climate shocks such as fires and flooding are generally localized to specific geographic areas, the COVID-19 pandemic had nationwide and global impacts. All stages of the agri-food system were directly affected by the pandemic or by responses put in place to reduce transmission of the virus. Agricultural production was heavily impacted by the closure of international borders, which reduced the workforce available to harvest produce.

> *Normally, we have 141,000 [working holidaymakers] in the country. We're now down to about 80,000...Growers are concerned that they can't get the product that they've already got planted off - so picked and packed and into the supply chain. - Interview 26, industry*

The COVID-19 pandemic affected food processing, manufacturing and distribution in several ways. Imports slowed

TABLE 2 Participant characteristics.

| | Food system stage | | | | | | |
|---|---|---|---|---|---|---|---|
| | Production | Processing and distribution | Retail | Consumption | Waste resources | All | |
| **Government** | 10 | 2 | 0 | 3 | 2 | 3 | 20 |
| **Industry** | 2 | 5 | 4 | 0 | 0 | 0 | 11 |
| **Civil society** | 2 | 0 | 1 | 6 | 0 | 1 | 10 |
| | 14 | 7 | 5 | 9 | 2 | 4 | 41 |

during the early months of the pandemic, which led to shortages of some raw ingredients and food packaging used in food processing.

> *We don't grow tea or coffee here in Australia in any volume. We don't grow cocoa for chocolate, so they're key ingredients…then there are also specialist flavours, food additives, vitamins and minerals that go into food products. Then there's packaging - the material…a lot of that comes from overseas. - Interview 3, industry*

Food manufacturers and wholesalers sought to import goods from elsewhere. However, as one participant noted, "the problem with pandemics is that it affects everyone, so those options for alternative sourcing aren't necessarily there" (interview 8, government). Agri-food exports from Australia declined as international ports closed or operated under restricted conditions. The grounding of passenger aircraft had a significant impact on perishable exports, such as horticultural produce and seafood.

> *Ninety per cent of our freight [fruit and vegetables] goes out under passenger aircraft and there's no passenger aircraft going. It's simply not cost-effective to go by freighter, dedicated freighter plane. - Interview 16, industry*

Food processing and distribution were affected by pandemic lockdowns and social distancing measures that restricted the number of workers allowed in some workplaces. For example, restrictions on workforce capacity in meat processing plants led to meat supply problems in supermarkets in Victoria, which forced retailers to look to other states to fill supply gaps.

> *In Victoria, we went to 60 per cent capacity at our meat plants, so that really did drive some challenges from meat supply in Victoria. We were bringing meats in from WA, Queensland and other places - Interview 34, industry*

There were rising food prices and supermarkets ran out of some staple foods, including pasta, rice, fruits, vegetables, poultry and meat. The hospitality sector was heavily impacted as restaurants, cafés and pubs were forced to close, leading to significant food waste and loss, as described by these interviewees from businesses and farms supplying into hospitality.

> *We're talking millions of dollars of stock that they were sitting on, that overnight the government said you can't supply these outlets any longer. - Interview 23, industry*

> *It was a lot of farmers losing their markets with the closure of hospitality industries, some of them not knowing where they're going to divert their produce to, and particularly some of those bigger ones just who exclusively supply to hospitality being faced with ploughing crops back into the soil. - Interview 13, civil society*

While some of the stock normally destined for the hospitality sector was diverted into supermarkets or food relief, participants explained that capacity to do this was limited due to differences in product size and volume for hospitality vs. household use. Widespread job losses and loss of income, particularly in the food industry, led to a steep rise in food insecurity and demand for food relief, including from those who had never accessed food relief before.

> *Demand is coming from a number of areas, one is young people, another is asylum seekers and international students, and the third one is entirely new cohorts of people that have never…sought help in the past. - Interview 7, civil society*

Figure 1 depicts participant perspectives on the impacts of the fires and the pandemic across the agri-food system.

### 3.1.3. Multiple compounding shocks

The compounding effects of multiple shocks to the food system was a key concern raised by participants. Years of drought were followed by the 2019–2020 Australian forest fires. While communities were still dealing with the aftermath of the fires in early 2020, the COVID-19 pandemic began. As the pandemic lockdowns and restrictions continued into 2021, extreme flooding affected large parts of eastern Australia. Participants highlighted the effects of these concurrent and overlapping shocks on communities and their workforces.

> *In the midst of COVID, the town's now under water but it was bushfire-ravaged in December-January. So, these poor people have just been kicked in the guts…for some period of time. There's the human toll that it takes and…also the economic and the business toll. - Interview 23, industry*

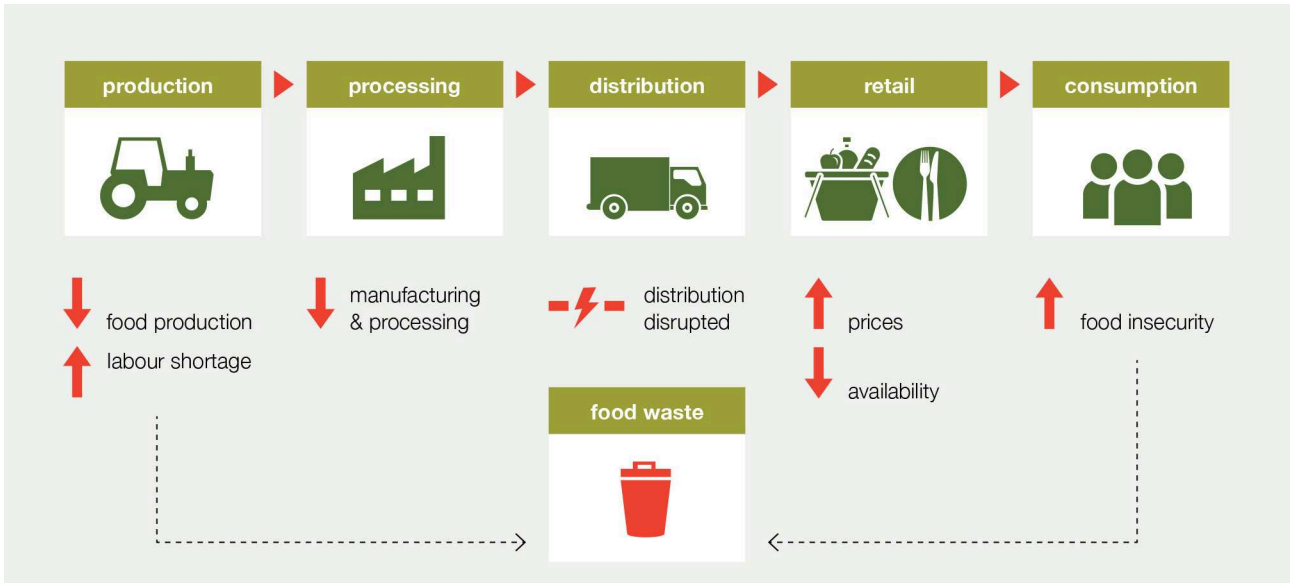


FIGURE 1
The reported impacts of forest fires and the COVID-19 pandemic across the agri-food system (from Murphy et al., 2022).

Participants noted that the compounding effects of successive shocks were greatest on those already experiencing disadvantage.

> *The people who are just scraping through beforehand are the ones who are going to be the most vulnerable when an acute shock hits. - Interview 6, civil society*

## 3.2. Vulnerabilities in the agri-food system

The forest fires and COVID-19 pandemic revealed critical vulnerabilities in Melbourne's city region food system.

### 3.2.1. Geographic and corporate concentration

The concentration of food processing and distribution centers clustered in particular geographic locations around Melbourne's city region is a vulnerability in the city's system of food distribution. One interviewee identified how a potential shock affecting a major bridge connecting one side of the city to the other is a key risk.

> *If [the West Gate bridge] ever stopped, it would be horrendous…all our fuel is in the west of Melbourne, all our [food] warehousing is in the west of Melbourne. How is it going to get to the east of Melbourne where half to two thirds of the population of Melbourne live? - Interview 17, industry*

Corporate concentration in supermarket distribution and retail was also identified as a vulnerability. During the pandemic, closure of supermarket distribution centers in Victoria for deep cleaning when staff tested positive for COVID-19 was perceived to be a pressure point.

> *It just takes a break-out at one of the distribution warehouses at [supermarket chain A] or [supermarket chain B] and then…they're going to run out of vegetables…it's concentrated in a very small amount of hands at distribution. I think there's a real risk around that longer term - Interview 20, government*

### 3.2.2. "Just in time" supply chains

Long and lean supply chains were perceived to be a key vulnerability during the pandemic. Surges in consumer demand for food during lockdowns led to a "five-fold uplift in demand of product" that could not be met because the major food retailers "run a very tight supply chain" (interview 3, industry). Participants reported that manufacturers increased production by working 24 h a day, seven days a week to meet increased consumer demand. However, capacity constraints in distribution networks slowed delivery to supermarkets.

> *When we get a rush in demand, the distribution centres don't have an ability to change gear…all of a sudden they need 200 trucks in [that] they haven't got the capacity to take. - Interview 17, industry*

Disruption to road and transportation networks in fire-affected areas also delayed deliveries of food to some supermarkets during the 2019–2020 forest fires. Participants described similar disruption to road and rail networks during other climate shocks, such as floods, which affected food deliveries.

### 3.2.3. Critical infrastructure

Agri-food systems are closely linked to and highly dependent on the continuing functioning of other systems, including energy, telecommunications, banking, transportation networks and logistics. Each of these systems was impacted in some way by the 2019–2020 forest fires or COVID-19 pandemic, compromising the food supply. During the fires, participants reported breakdowns in power, telecommunications, and banking that limited access to fuel, food and other groceries. Road and rail closures during fire and flood disrupts movement of food and livestock and impacts the quality and availability of fresh produce.

> *There's 257 kilometres of railway track impacted by floods in the last couple of weeks. That really restricts the ability to move product around the country. - Interview 34, industry*

One participant noted that even in ordinary times, "we have one of the most difficult tasks in Australia to supply goods over a long distance" (interview 31, industry) with high ambient temperatures, low population density, and long-haul freight distances to travel. Interstate border closures in Australia during the COVID-19 pandemic also delayed food freight at times.

### 3.2.4. Workforce

The workforce in agri-food production, processing, distribution, retail and food relief sectors were all affected by the pandemic, and to some extent by forest fires. Participants described labor shortages in agriculture when international borders closed during the COVID-19 pandemic. Workforce density limits were also introduced in meat processing plants and supermarket distribution centers, and there were complete shutdowns across the hospitality sector. The food relief sector lost its volunteer workforce "almost overnight" because "the bulk of our workforce—the volunteers—are over 65, and at higher risk in the COVID environment" (interview 12, civil society). Loss of income and employment led to rising food insecurity, including in the food industry workforce. One participant noted:

> *Covid-19 has helped put in people's mind the fragility of their own employment status and how anyone can find themselves in this predicament. - Interview 4, civil society*

One participant perceived workforce availability as the most significant vulnerability revealed during the COVID-19 pandemic, "we've got the resilience in the supply chain if we can overcome the labor elements" (interview 34, industry).

Climate and pandemic shocks exposed vulnerabilities in the agri-food system that led to temporary food shortages, rising prices for some foods, and growing food insecurity. However, overall, the food system continued to supply enough food to feed most Victorians and showed aspects of resilience. The following section identifies the features of the agri-food system that contributed to resilience.

## 3.3. Features of a resilient agri-food system

Participants discussed factors that contributed to a more resilient agri-food system with capacity to withstand and recover from shocks and stresses.

### 3.3.1. Diversity

Diversity was identified by interviewees as a feature that helps agri-food systems to withstand a sudden shock. Diversity in where food is produced can build resilience as food can be sourced from other growing regions when one region experiences a shock, such as an extreme weather event. Diversity in where food is sourced from also provides contingency if disruptions in transportation networks or other infrastructure impede food deliveries to or from particular geographic areas. Diversity in types of transportation builds redundancy into food systems, as described by this participant.

> *From a transport side of things, we have a diversified network to support major disruptions, which can switch between rail, road, coastal shipping and air freight to ensure adequate supply is available. - Interview 21, industry*

Diversifying the type of crops grown can safeguard against climate change by spreading risk. For one participant, diversity in production meant reducing reliance on imported foods and ingredients and "growing as much [as possible] of what we want to eat in Australia within Australia" (interview 28, industry). Another participant acknowledged there was diversity in production but had concerns about the lack of diversity in food processing and manufacturing.

> *There's two major meat processors in the country - there's heaps of growers so there's diversity of production, but the key bottlenecks are [meat processors]. Same with dairy, we've only got six dairy processors. - Interview 16, industry*

Diversity in the scale, length and types of supply chains also strengthened resilience. During the first Omicron wave of the COVID-19 pandemic in early 2022, supermarkets ran short of many fresh foods due to the number of workers isolating through food supply chains, while small independent grocers and food markets often had good supplies as they sourced foods through shorter, more localized supply chains. One participant explained:

> *A small-scale autonomous business able to duck and weave, to protect itself, to represent itself, to tell its story, to change course if necessary and have strong relationships, both with customers and its peers and its cohort. I think it makes for a very robust group of people and businesses. - Interview 5, industry*

Another participant noted that, "we want to make sure that we've got a range of supply chains, not just relying on the bigger, traditional chains…I guess, armouring ourselves

with as many sources of food as we can" (interview 12, civil society).

### 3.3.2. Decentralization

Some interviewees perceived that decentralized agri-food systems increase their resilience by spreading food processing, distribution and retail across a greater number of organizations and locations. This responds to vulnerabilities associated with concentrating food system infrastructure in a small number of geographic areas and food industry workers and power in a small number of organizations.

> *Whether it's a workforce shutdown, a pandemic, a bushfire, or whatever else, you've got multiple [nodes] that are carrying 10 per cent of volume each rather than two big nodes which are 50/50. - Interview 16, industry*

Decentralizing food systems creates redundancy and supports diversity. It can also strengthen local and regional food supply chains that more directly connect producers and consumers by investing in small-scale food processing facilities in regional areas.

### 3.3.3. Adaption and innovation

Adaption and innovation are positive responses among food system actors that strengthen resilience and promote recovery after a shock. Major retailers adapted to the forest fires by rerouting food freight away from major highways in fire-affected areas to alternate transport routes. They established "pop-up" distribution centers to respond to increased consumer demand for food during the COVID-19 pandemic and by-passed distribution centers altogether at times.

> *The supply chain had to adapt…the classic distribution is manufacturer, distribution centre…and out to supermarkets. They were circumventing that by sending trucks straight from the manufacturer directly to supermarkets, to keep the supply up. - Interview 3, industry*

There was also innovation and adaptation in short food supply chains that connect producers directly to consumers. Many small-scale growers who sold through farmers markets and farmgate shops moved quickly to online sales during the COVID-19 pandemic.

> *A lot of organisations are incredibly resilient, they're incredibly adaptable and flexible. We've certainly seen that during this COVID-19 period where organisations have really pivoted…they've just switched the service delivery from face to face to on the phone to online. - Interview 7, civil society*

### 3.3.4. Networking and collaboration

Networking and collaboration between stakeholders throughout agri-food systems was perceived to be a key feature of resilience. Partnerships foster a collaborative way of working and "collaborative policy responses across organizations" (interview 1, government). Networks based on strong relationships and trust can support a rapid response when activated in times of crisis.

> *The point of these networks is that when you get a call in the middle of the night, it's from somebody that you know and trust…so when you come together, there's not that necessary storming piece. You've already formed. - Interview 8, government*

Participants from government, industry and civil society all emphasized the importance of networks and collaboration. Strong community networks build resilience by fostering local solutions.

> *I think we're going to need to move to a place of local networks and network solutions and resilience systems, rather than try to go macro. - Interview 6, civil society*

### 3.3.5. Sustainable livelihoods

The COVID-19 pandemic magnified existing vulnerabilities in workforce availability in the agricultural and food industries. Several participants emphasized the need for a reliable "dedicated workforce to work in horticulture" year-round in Victoria (interview 26, industry). Another participant highlighted challenges to the viability of farming, arguing that if farmers were "properly remunerated for their product" (interview 12, civil society), it would increase the resilience of the agri-food system.

> *I think a resilient food system is where people know who grows their food, they have a relationship with them, the farmers are paid fairly, therefore they have a better chance of running a viable business and can continue to adapt and evolve and innovate. - Interview 13, civil society*

Sustainable livelihoods in food enterprises and farming underpin a resilient food system. However, the experience of the COVID-19 pandemic points to the need for greater action to support fair farmgate prices and fair and safe working conditions.

## 3.4. Preparedness

Participants in our research emphasized the importance of learning from shocks such as forest fires and the COVID-19 pandemic to strengthen the resilience of agri-food systems to future shocks. Interviewees noted that food systems are now experiencing multiple and concurrent shocks and stresses, and that there is a need for more strategic, long-term planning to build the resilience of food systems.

> *I think they [the government] need to think strategically and do long-term planning and not just look at the next two to three years but look at 5 to 10 years. Because if you take the [forest fires] and floods, we see it on a regular basis…the pandemic can happen again. I think we need to start thinking longer term. - Interview 21, Industry*

Participants spoke about need to use the experience of the COVID-19 pandemic and recent climate shocks as a moment for "transformational thinking".

> *The tip of the iceberg is just getting by from cycle to cycle, from disaster to disaster and keeping your head above water. The next level down is systemic change, changing how you do things to better respond to be better prepared. Then there's a whole iceberg of transformational adaptation where you're fundamentally re-imagining your objectives in the first place… those sorts of really big questions, sometimes space is created for them off the back of a disaster. - Interview 19, government*

In addition to taking action to prepare agri-food systems for future climate and pandemic shocks, our interviewees were conscious of the need to prepare for other potential shocks such as "geopolitical events [that] can just shut supply chains" (interview 3, industry), and cyber-attack "with the potential for massive disruption [and] damage to food supply chains" (interview 8, government).

Participants emphasized that preparedness planning should focus on actions that will build the resilience of agri-food systems to any future shock, to "future-proof ourselves by keeping those (community resilience) principles hazard blind" (interview 6, civil society). Another participant noted:

> *These sorts of overlapping shocks and stresses… what is their common denominator? What is the thing that is going to strengthen us to better prepare for any of those things happening, and then, which is more of a hazard agnostic approach? - Interview 1, government*

Participants highlighted the importance of also taking action to address the impacts of underlying environmental stresses on agri-food systems, such as biodiversity loss, decline in pollinators and pressure on the availability of water and agricultural land.

> *Deteriorating environmental conditions remains the slow-burn shock that most policy makers are really thinking about. - Interview 2, government*

Some of our interviewees recognized that there are interactions between climate and pandemic shocks and the long-term environmental stresses facing Melbourne's food system that were of significant concern.

> *This whole question of the integration between climate and ecology is going to be a big [issue]. The fact that we're losing our ecosystems at a really rapid rate is going to be one of the biggest issues as we go forward. - Interview 29, government*

## 4. Discussion

This study investigated stakeholder perspectives on the impacts of climate and pandemic shocks on the agri-food system in Melbourne, Australia. Our findings showed that there were short-term, localized impacts from the forest fires throughout the food system, which was able to recover within a timeframe of weeks to months. By contrast, the pandemic placed significant stress across the whole agri-food system that was not bound by geographic area, and that continued over time. A key goal of a resilient food system is to provide food security for all (Tendall et al., 2015). Food insecurity increased during the COVID-19 pandemic due to lockdowns, loss of income and rising food prices (Louie et al., 2022). A Foodbank Australia survey in 2022 found that 21 % of Australian households had experienced severe food insecurity in the previous 12 months, and that almost one third of households with children had experienced severe food insecurity (Foodbank Australia, 2022). Our findings show how the compounding effects of multiple, overlapping shocks and stresses on the agri-food system contributed to food insecurity.

We identified vulnerabilities across the agri-food system to these shocks. Geographic and corporate concentration in meat processing, supermarket distribution and retail reduced capacity within the system to absorb the shocks and offered little redundancy within supply chains to switch to other options. MacMahon et al. (2015) and Love et al. (2021) also identify concentration in agri-food systems as a vulnerability with potential to increase food insecurity. Similar to other studies, long and lean supply chains were identified as a vulnerability (MacMahon et al., 2015; Zeuli et al., 2018; O'Meara et al., 2022), as well as international supply chains and logistics networks (Ali et al., 2022; Jones et al., 2022). Consumer demand surges on Melbourne's "just in time" food supply chains during the pandemic led to food shortages and heightened food insecurity (Carey et al., 2020; Louie et al., 2022). The failure of other systems that food supply chains rely on—such as transportation, energy, telecommunications, and banking—heightened the risks of "just in time" food supply chains and compromised the functioning of the agri-food system. The vulnerability inherent in interdependencies between agri-food systems and other critical infrastructure is widely acknowledged (Zeuli et al., 2018; Newell and Dale, 2020), and has led to the development of critical infrastructure resilience networks and plans (Victorian Government, 2022). Labor availability and workforce issues in the agri-food system were a vulnerability during the COVID-19 pandemic, as highlighted by similar studies in Australia (Snow et al., 2021; Jones et al., 2022), and internationally (Luckstead et al., 2020; Hobbs, 2021; Waltenburg et al., 2021).

Features of the agri-food system that supported resilience included diversity and decentralization. Diversity of commodities, actors and sources of food is central to the resilience of food systems in the context of multiple shocks and stresses (FAO, 2021). In the present study, there was diversity in production and sources of food, in transportation and food distribution networks, and in the scale, length and type of food supply chains. When the long supply chains of the major supermarkets ran short of fresh foods, the shorter supply chains of independent grocers, farmers markets and fresh produce markets were able to continue supplying these foods. Other studies have similarly found that long and complex supply chains were particularly impacted during the COVID-19 pandemic (Rivera-Ferre et al., 2021; Stoll et al., 2021). A number of studies have highlighted the importance of local decentralized food supply chains to resilient agri-food systems, as they are nimble and flexible and can adapt and innovate quickly (Thilmany et al., 2020; Blay-Palmer et al., 2021; Marusak et al., 2021; Cattivelli, 2022). A

combination of long and short supply chains can strengthen the resilience of agri-food systems to shocks and stresses and their capacity to promote food security (James and Friel, 2015; Smith et al., 2016; FAO, 2021).

Innovative responses from food system actors can build resilience to shocks and contribute to food security (FAO, 2021). Innovative adaptions were evident in both long and short supply chains in the present study. They included the "pop-up" distribution centers established by the major retailers during consumer demand surges, and the new online distribution channels established to support small-scale farmers who supply direct to consumers and businesses. These innovative responses were facilitated by networks and collaboration among food system actors, a finding supported by other studies (Snow et al., 2021; Jones et al., 2022). Multi-sectoral collaborative approaches are important to build the resilience of agri-food systems, together with integrated policy approaches that consider how interdependencies with other systems impact the resilience of agri-food systems (FAO, 2021).

Sustainable livelihoods in agri-food enterprises were also revealed as a central feature of resilient food supply chains through our study. Work in the agri-food industries in Australia is frequently casualised and insecure, with low pay and poor working conditions (Jones et al., 2022; Murphy et al., 2022). Our findings highlight the importance of policy action to address workforce issues for food system resilience (Carey et al., 2022). Other studies have also recommended policy action to ensure labor availability and sufficient farm income, and for social protection to protect livelihoods (Savary et al., 2020; Fan et al., 2021b).

Our study highlights how resilient agri-food systems need to be prepared to cope with the compounding impacts of multiple shocks and stresses that co-occur or overlap. Agri-food systems are currently ill-prepared for the increasing frequency and severity of shocks (Fanzo et al., 2021). In Australia, the compounding shocks of forest fires and the COVID-19 pandemic—and more recently, extensive flooding and Russia's invasion of Ukraine—have challenged the capacity of the agri-food system to deliver food security for all and protect livelihoods (Murphy et al., 2022). The main focus in resilience building in agri-food systems has been on reactive strategies that build capacity to cope with shocks over the short term, There now needs to be a greater focus on longer-term adaptive and transformative strategies (Love et al., 2021).

As shocks to food systems increase in frequency and severity, there are growing calls for food system transformation to increase resilience, promote global food security and build equitable and sustainable food systems (HLPE., 2020; FAO, 2021). Food system transformation moves beyond adaptive responses that adjust or incrementally change activities within specific stages of the food system such as agricultural production. Instead, it changes the outcomes of the overall system, including food security, environmental outcomes and socio-economic outcomes (Ingram and Thornton, 2022). Many researchers have noted the potential for transformative change in global food systems following the COVID-19 pandemic (Blay-Palmer et al., 2020; Rippon et al., 2020; Savary et al., 2020). Transformative change that strengthens the resilience of agri-food systems is needed to progress the United Nations Sustainable Development Goal to End Hunger (FAO, 2021).

Our study has shown that resilient agri-food systems need to be prepared for any shock, both known risks, such as forest fires during summer in south-east Australia, and those that are unforeseen. Our study has also shown that resilience building in agri-food systems requires a greater focus on building resilience to both sudden shocks and underlying environmental stresses, and to the cascading impacts that result from interactions between both (Zurek et al., 2022). This study makes an important contribution to research about the perceived impacts of multiple shocks and stresses on agri-food systems. To our knowledge, this is one of the first empirical studies that has investigated the views of multi-sectoral food system stakeholders on the impacts of multiple shocks and stresses on the agri-food system in an Australian context.

Our study had a number of strengths. First, it adopts a multi-sectoral approach with participants from government, industry and civil society, who shared perspectives on the effects of recent shocks on the effects of recent shocks throughout the agri-food system, from production to consumption and waste. Second, the timing of the study—which commenced as forest fires and the COVID-19 pandemic were disrupting the agri-food system—provided insights into the impacts of multiple, overlapping shocks and stresses on the agri-food system as events were unfolding. However, this is also potentially a limitation of the study. If participants had longer to reflect on the events, their perspectives may have been different. The study was also situated in a city region of a high-income country. Hence, the generalizability of findings to other contexts, particularly low- and middle-income countries, may be limited.

## 5. Conclusion

This study investigated the resilience of agri-food systems to shocks and stresses using a case study from Melbourne, Australia. Compounding shocks to agri-food systems from climate events, pandemics, geopolitical conflict, and the ongoing decline of natural ecosystems highlight the need for a better understanding of ways to build food system resilience. Food resilience planning and policy initiatives are needed at all levels of government to promote diversity within agri-food systems, decentralization, adaption and innovation, networking and collaboration, and sustainable livelihoods.

Our study found that the resilience of agri-food systems needs to be strengthened to a range of future shocks and stresses, and to the cascading effects of interactions between them. Further research is needed to investigate interactions between the effects of climate and pandemic shocks on agri-food systems and the effects of ongoing environmental stresses, including biodiversity loss and declining natural resources. Policy to promote the resilience of agri-food systems will also increasingly need to focus on transformative actions that build long-term resilience to any future shock.

## Data availability statement

The datasets presented in this article are not readily available because of participant privacy. The data consists of transcripts of semi-structured interviews. Through the participant consent process, we agreed to protect the

anonymity of participants. Participants may be identifiable from the transcripts, and so the data cannot be made publicly available. Requests to access the datasets should be directed to MM, maureen.murphy@unimelb.edu.au.

## Ethics statement

The studies involving human participants were reviewed and approved by the University of Melbourne Human Research Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

RC conceived of the study and wrote sections of the manuscript. MM, RC, and LA performed qualitative interviews and analyzed qualitative data. MM wrote the first draft of the manuscript. All authors reviewed and edited drafts of the manuscript, read, and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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