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Resilience achieved via multiple compensating subsystems: The immediate impacts of COVID-19 control measures on the agri-food systems of Australia and New Zealand

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ABSTRACT

Context: Since COVID-19 (SARS-CoV-2) was first identified in the human population, it has had immediate and significant effects on peoples' health and the worldwide economy. In the absence of a vaccine, control of the virus involved limiting its spread through restrictions in the movement of people, goods and services. This has led to unprecedented impacts on labour availability, provision of goods and services, value chains, and markets.
Objective: Against the backdrop of COVID-19 control measures, this article summarises quantitative and qualitative assessments of the impacts, adaptations, and opportunities to increase the resilience of the agricultural systems in Australia and New Zealand.
Methods: Using both survey and interview methodologies, we describe the various agri-food systems and the impacts of the COVID-19 control measures across different industries, and discuss the results applying a resilience framework.
Results: As essential services, all agricultural activities except for fibre production have been permitted to continue during quarantine periods but have been exposed to the major flow-on effects of movement control. We found that, to June 2020, the impacts of the COVID-19 control measures on the agri-food sectors in both Australia and New Zealand have been relatively small and that this has been due to the high levels of resilience in the agricultural systems and the people running them.
Conclusions: We consider agri-food systems to be comprised of multiple subsystems with varying vulnerability to external influences. Agri-food systems were resilient to June 2020 at least, and that resilience was achieved via one or more subsystems that were able to compensate for the more vulnerable subsystems. We contrast the resilience of industries that have high plasticity (that can have a flow of material that can safely vary in time) to more rigid industries that are dependent on a steady flow of material with little or no storage. Ultimately both types of industries were resilient, but they achieved that resilience via compensating subsystems. High plasticity

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industries relied on their production and processing subsystem; rigid industries engaged their institutional subsystem to achieve the same end. The social and cultural subsystem was important across all industries.
Significance: It is not yet clear if the current resilience mechanisms can persist under the continued onslaught of the virus. We indicate the need to capture longer term effects and analysis during the more sustained effects of the virus and through a recovery period. We anticipate a follow-up study in 2022.

1. Introduction

In the short time since COVID-19 (SARS-CoV-2) was first identified in the human population, the virus had an immediate and significant effect on public health and the worldwide economy. At the time of writing this article (late-November 2020), nearly 58 million infections and 1.3 million deaths have been reported worldwide (World Health Organisation, 2020). In the absence of a vaccine, control of the virus involved limiting its ability to spread through the population. In some countries, this led to unprecedented restrictions on people, goods, and produce movement, and impacted labour supply, provision of goods and services, value chain operations, and markets. These controls considerably slowed economies, with the World Bank (2020a) predicting the deepest global recession since World War 2.

As an essential service, agricultural activities have largely been permitted to continue during quarantine periods, although the sector was still exposed to the flow-on effects of movement restrictions and market disruptions (Stephens et al., 2020). In Australia and New Zealand, impacts were anticipated through (Fig. 1):

- reductions in the availability of agricultural inputs (e.g. agrochemicals) and/or crucial replacement parts for equipment;
- reductions in the availability of specialised and non-specialised labour following from restrictions on seasonal migrant and working holiday schemes, or inability of individuals to work (e.g. high health risk, family care needs);
- difficulties with the distribution of agricultural products from farm gate to processing facilities, and from there to final sales locations;
- reduced capacity in processing plants resulted from physical distancing regulations and operational inefficiencies; and/or
- changes in market demand.

Inspired by the diagrammatic view of the agri-food system created by Nourish (n.d.) we hypothesised that the major impacts (as listed above and Fig. 1) would be moderated by multiple, interacting and compensating, sources of resilience across dimensions of the production and processing system, the economic system, institutional activities, social and cultural interactions, and from the environment. These are depicted in Fig. 1 as recycling arrows.

Stephens et al. (2020) noted the need to capture and record the short-term effects of the pandemic and its control measures on agricultural systems to provide insights and identify a baseline impact for future comparisons. This article summarises quantitative and qualitative assessments of impacts, adaptations, resilience levels, and opportunities in the agricultural systems of Australia and New Zealand. These OECD countries are linked geographically and economically, receive a significant proportion of their export earnings from agricultural activities, and have similarly advanced agricultural systems (DFAT, 2020). Nevertheless, there are differences in the challenges faced by each country. For example, the COVID-19 restrictions coincided with the end of drought conditions in some regions of New Zealand. Australia, in contrast, has endured widespread and protracted drought conditions for several years (http://www.bom.gov.au/climate/drought/), in addition to extensive economic and biophysical losses from bushfires that affected Eastern, and South Eastern Australia during the summer of 2019-20. The two countries have contrasting agroecological conditions, exposures to climate variability, composition of their agricultural export markets, and levels of production intensity and scale, sizes of population, and internal and external markets. These similarities and differences make for a potentially informative analysis of the effects of COVID-19.

Following the call from Stephens et al. (2020), our objective was to understand the immediate, to June 2020, impacts of the control measures against COVID-19 on the agri-food systems of Australia and New Zealand. Below, we describe the agri-food systems of both countries, explore the impacts from COVID-19 control measures across the different agricultural industries, and discuss the results from surveys and interviews with practitioners and key players from the most relevant agricultural industries of each country. Note that the survey and interviews, and thus the findings in this article, are constrained to the period January-June 2020. Using the information from the survey and interviews, we reanalyse Fig. 1 in the context of the multidimensional resilience framework suggested by Fielke et al. (2018) to better understand the mechanisms of resilience. Finally we note some of the possible longer-term effects of COVID-19 on the agri-food systems of the two countries.

2. Agri-food systems and COVID-19 control measures

2.1. Primary industries and their role in the Australian and New Zealand economies

Australia's 384 million ha of agricultural land supports ~89,000 agricultural businesses with 332 million ha of grazing (primarily extensive sheep and cattle but some dairy), 31 million ha of crop production, and 0.8 million ha of plantation forestry, with the remainder in conservation or other uses (Australian Bureau of Statistics, 2020). The agricultural sector employs around 334,000 people, representing 2.6% of the Australian workforce. The value of Australian agricultural exports has remained around USD 36 billion[1] for the past three years, and this represents around 18% of Australian goods export earnings (Australian Bureau of Statistics, 2020). In 2019/20 the estimated gross value of agricultural production was USD43 billion. Australia exports nearly two-thirds of its agricultural production. Major export commodities are beef and veal; lamb, wool and mutton; wheat and barley; sugar, oil seeds and cheese (Howden et al., 2020).

In New Zealand the primary production sector (agriculture, fisheries and forestry) comprises ~65,000 businesses (Statistics New Zealand, 2020a) and, including food production, employs around 11% of the country's 2.6 million workforce (New Zealand Immigration, 2020). The agricultural sector generates USD 31 billion, nearly two-thirds of New Zealand goods export earnings (Statistics New Zealand, 2020b). The top three export commodities by value are dairy, meat and wood, amounting to almost 45% of the value of total merchandise exports with dairy products alone accounting for around 24% (Statistics New Zealand, 2017). New Zealand's agriculture is primarily export-oriented with dairy, meat, fisheries, wine, forestry and some horticulture sectors exporting 70–95% of their production (New Zealand Foreign Affairs and Trade, 2020). The exceptions to this are the cropping and fresh produce sectors, which have both domestic and export markets, and the pork and chicken industries where production is primarily for domestic consumption (Ministry of Primary Industries, 2019; New Zealand Pork,

[1] We have assumed conversion rates of 0.71 AUD and 0.66 NZD per USD based on the three-year averages from https://www.ofx.com/en-nz/forex-news/historical-exchange-rates/yearly-average-rates/.

2018).

2.2. COVID-19 control measures and governmental responses

2.2.1. Australia

Social distancing was first introduced in Australia in March 2020. On 17th March 2020, Australia banned arrivals of visitors and required all arriving residents to self-isolate for two weeks, significantly reducing the number of seasonal and migrant workers. Domestic lockdown measures were introduced on 23rd March, closing or restricting access to venues where people clustered. These restrictions were ramped up during March, and by 29th March, Australians were urged to stay at home other than for food shopping, medical or care needs, exercise or work/education that could not be done from home.

On 12th March 2020, the Australian (Commonwealth) Government announced its first round of business financial assistance (USD 12 billion) through tax relief subsidies and welfare payments to workers stood down or made jobless. A further round of financial assistance was announced on 30th March 2020 with USD 92 billion in wage subsidies. While these subsidies were not directly for agriculture, they were likely to have indirectly supported domestic demand.

Each Australian state and territory has the legal authority to declare emergencies and make orders to deal with an emergency. After 25th March, some states and territories in Australia (e.g. Tasmania, South Australia, Northern Territory, and Western Australia) closed their internal borders to non-essential travel. Food production and agriculture were classified as essential but still subject to distancing requirements.

The Commonwealth Government, via the International Freight Assistance Mechanism, has supported the export of high-quality produce, such as seafood, into key overseas markets, which will continue until the end of 2020 (Business.gov.au, 2020). The availability of seasonal harvest workers for fruit and vegetable picking, harvesting, and shearing, remain a concern due to the closure of the international border.

2.2.2. New Zealand

From 3rd February 2020, New Zealand implemented a ban on travellers from China, introduced a requirement on 16th March that all incoming travellers self-isolate for 14 days, and closed its borders on 19th March 2020 to all but returning citizens and residents. These bans dramatically reduced international arrivals; international aircraft movements declined by 82% in April compared to the three previous years (Auckland Airport, 2020).

Internal controls on movement in New Zealand started on 21st March 2020, but the effects of reduced tourism were already being felt. Data from MBIE (2020) suggest that international tourists account for 2–4% of the country's population at any point in time. While agriculture was not directly affected, the reduction in tourist arrivals substantially affected demand for agricultural products through the restaurant and fast food trade, both of which were shut down. On 17th March 2020, the New Zealand government announced the COVID-19 support package of USD 8 billion (The Treasury, 2020). Major support measures included a large wage subsidy and leave schemes, a loan guarantee scheme for small and medium enterprises and tax deferrals and reliefs. These schemes were contingent on critical levels of reduced revenue for businesses, and while agricultural businesses rarely qualified, they were important in maintaining domestic demand. In May 2020, the government established the COVID-19 Response and Recovery Fund as a part of Budget 2020 and set aside USD 33 billion to support a response to and recovery from COVID-19 for the next four years (Robertson, 2020).

During the COVID-19 response, the New Zealand government worked closely with primary sector leaders to identify the challenges faced and to develop safe work practices. The main non-labour issues were air freight challenges for exporters of high-value products and loss of key markets. In addition, some sectors were concerned with impending shortages of some animal feed components (Ministry for Primary Industries, 2020). The government intervened by providing USD 218 million of financial support for international air-freight carriers to ensure high-value exports could reach global markets and essential imports could arrive in New Zealand. Initially, 53 weekly flights were scheduled to main export destinations, and at the beginning of August, the schedule was increased to 70 flights per week (Ministry of Transport, 2020). These measures are planned to be in place until at least the end of November 2020.

Animal feed availability was a key concern for livestock farmers, particularly because the pandemic coincided with a widespread autumn drought. COVID-19 and related measures resulted in some farmers having to hold stock on-farm through the 2020 autumn, when slaughter was delayed due to processing constraints. The government worked to ensure that critical services and essential imports (e.g. animal feed, farm machinery) to farms and food production systems were provided (Ministry for Primary Industries, 2020).

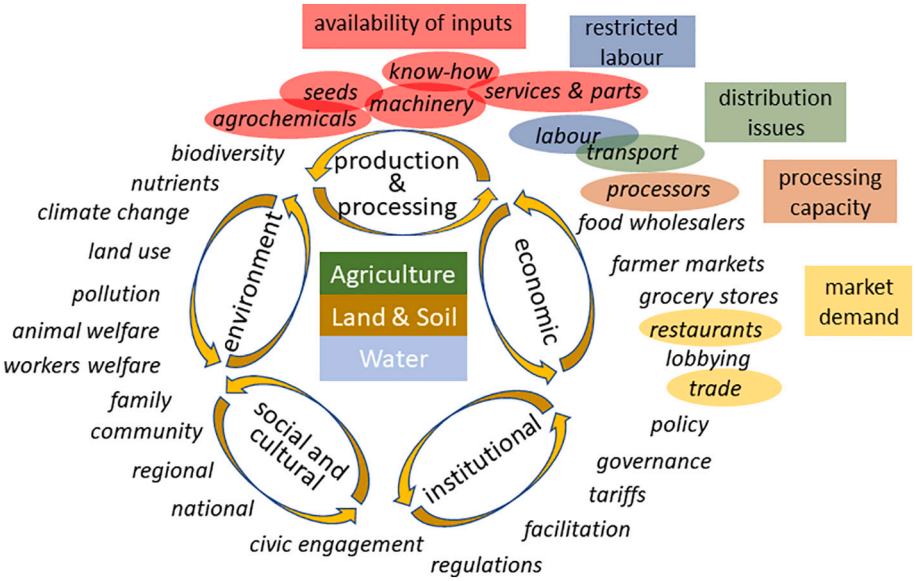

Fig. 1. Diagrammatic view of the agri-food system adapted from Nourish (n.d.) highlighting areas of anticipated direct impact of COVID-19 (coloured ovals). The subsystems ("social and cultural" etc.) depicted as recycling arrows are potential mechanisms of resilience.

Additional details of the quarantine actions taken by the New Zealand and Australian governments to control COVID-19 are given in Supplementary Materials (SM) SM1 and SM2.

3. Methods

Online surveys and targeted interviews were used to collect quantitative and qualitative data to understand the effects of COVID-19 quarantine measures on the agri-food systems in both countries. Ethics approvals for the survey and interviews were obtained from AgResearch under approval #9.20 with reciprocal approval by CSIRO under #084/20.

3.1. Online survey

An online survey was developed by the research team, iteratively and collaboratively over several weeks. The survey instrument can be found in the supplementary material (SM3). The survey included profiling questions about the respondent: location, role in the agri-food system, sector, and other information. Quantitative questions in the survey asked respondents about their experiences of the COVID-19 pandemic and resulting government actions across 13 aspects of their commercial operations. Four qualitative, open-ended, questions were included in the survey. These asked the respondent to comment on: the main problems experienced in their business; whether any new opportunities arose; any issues with production systems or supply chains; and what a 'new normal' might be for their business in two years (i.e. in mid-2022).

The survey was administered on the SurveyMonkey platform with respondents recruited using a combination of direct invitations via personal contact (email, phone, etc.) and personal and company social media posts. The posts were re-posted or shared by the organisations and researchers involved to increase reach. The survey opened on 9th July 2020 and closed on 10th August 2020.

The quantitative data were analysed using R version 3.6.2. The qualitative data were coded in two ways. Categorisation coding was first done using an iterative process by two experts in the sector from the authorship list. The steps involved proposing initial codes after scanning and discussing the responses, applying one or more codes to each response; adding more codes as more detailed reading and discussion of the responses proceeded; and finally, amalgamating any minor or apparently duplicate codes. The full coding schema, which is in SM3, resulted in 6–11 codes for each question. To validate the replicability of the coding, a third author independently coded the interview text, using NVivo 12 Plus; this was done separately with the exception that the same codes were used. Replicability was high.

Two analyses were done on the qualitative data: quantitative analysis of the frequency of codes across countries, role (e.g. processor, farmer) or sector (e.g. red meat, forestry); and qualitative analysis to generate word frequencies and extract meaningful comments.

3.2. Interview methodology

The survey was supplemented with targeted interviews conducted by the authors with key individuals in the agri-food sectors, e.g. farmers, business owners, company employees. The interview questions were designed iteratively with the authorship team and comprised five profiling questions designed to match those in the survey, and ten interview questions. The interviewers used the questions as starters and probed for further information and insights during the interviews. Interviewers transcribed the replies into an interview guide (given in SM4), which was verified with the interviewee before adding the completed guide to a central repository.

Forty-four interviews were completed between late July and early September. An R (version 3.6.1) script was developed to extract the interview replies into a consolidated document. This script detected and loaded the files, captured the interview file's form fields, applied rules to add consistency to some of the profiling data, and extracted the responses to a single CSV file for further formatting. The business rules did not change the underlying responses; rather, small changes were made to maintain consistency. The script, available as a zipped file in SM12, generated an RMarkdown HTML file confirming the integrity of the data. The script used the "docxtractr" R library (v0.6.5) to achieve the desired functionality (CRAN, 2020).

The consolidated CSV dataset was used, along with the survey information, to construct narratives on the overall effects of the COVID-19 control measures on industry sectors.

4. Results and discussion

4.1. Quantitative analysis of the survey responses

There were 321 responses to the survey (SM5) with similar numbers of responses from non-farmers across the two countries, and about twice as many responses from farmers in New Zealand than in Australia. A full analysis of the quantitative questions in the survey is given in SM5. Key points are given in Box 1.

4.2. Analysis of the response categories for the open-ended questions in the survey

The response codes (a code collates participants' responses to questions around emergent themes) for the open-ended questions are given in SM6, along with a short text description and full description of each category. The responses clustered into ten codes for the question on problems, eight for opportunities, six on supply chains and eight for the question on how their business might change post-COVID. A full analysis of the response codes is presented in SM7 with the main points given below.

Fig. 2 shows the frequency of each code as mentioned by respondents to the question about the problems encountered (Q11). There were

Overall, reported impacts were negative on average but included many neutral and some positive responses. Both countries reported similar magnitude of impact across sectors but *via* differing mechanisms. Some differences were found regarding ability to adapt, but are within expected variation.

Impacts on production: Many facets of farms and businesses were affected similarly, with Australia somewhat more optimistic. Impact on business risk was most noted and is worse for the majority. Farmers and non-farmers had different experiences of COVID-19 in some aspects:

- Farmers reported more negative impacts than non-farmers.
- Non-farmers reported a greater ability to adapt than farmers.

Duration of impacts was expected to last beyond July 2022. International issues and business risks were anticipated to have the longest duration, with no difference in the expectations between farmers and non-farmers.

- Access to domestic labour is expected to recover soonest.
- Profitability is expected to take the longest time to recover.

Ability to adapt ranged between no possible adaptions to those that were able to adapt substantially. Adaptations were across many different parts of a business, suggesting adaptation was complex and far-reaching. Overseas markets and international labour were least adaptable.

Box 1. Summary of the key findings from the quantitative questions in the survey. See SM5 for full details.

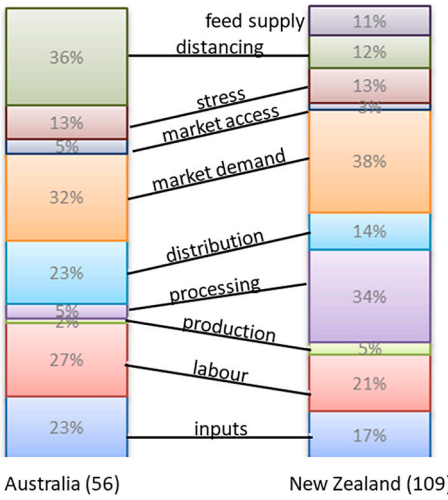

Fig. 2. Codes from the responses to the open-ended question about the problems experienced as a percentage of responses from each country. See the SM7 for additional detail and responses to the other questions. The text is the code label detailed in SM6. The values in parentheses are the total number of responses and the percentage values on the bars are the percentage of respondents that included text assigned to the given code.

commonalities in the code mentions across the two countries. As a percentage of responses from each country, issues associated with getting inputs, accessing labour, and problems with market demand, had similar frequencies. Other commonalities (see SM7) included: the pandemic provided an opportunity to consider workplace innovations (Q12), identifying inventory management and modifying their business as solutions (Q14), and identifying the likelihood of businesses being more agile and taking greater heed of health and safety (Q15).

There were also notable differences between countries. For example, feed supply was only mentioned by New Zealand respondents (Fig. 2) and this was likely due to the pandemic occurring at the end of drought conditions that had affected several regions of the country. Processing problems (Fig. 2) concerned a much greater percentage of New Zealand than Australian respondents. This was likely due to a combination of a greater proportion of New Zealand respondents being from the red meat industries (SM7) and the backlog in meat processing plants as a result of the drought and social distancing in New Zealand. Further, New Zealand respondents anticipated a greater emphasis on the domestic market (see SM7, Q15), but this category did not feature in the Australian respondents. These New Zealand respondents were primarily from the cropping (arable), pork and chicken sectors (SM7), which already sell most of their product in New Zealand, and they anticipated that their market will prefer locally produced goods in the future.

The detailed narrative analysis of the open-ended questions is given in SM8. Key points are noted below along with supporting quotes from some of the respondents. The most frequently used words were viewed as a proxy that represented participants' perspectives (Feng and Behar-Horenstein, 2019). Supporting this approach was the assumption that important and significant words would be used more frequently (Carley, 1993). 'Change' was the most frequent word discussed by respondents, regardless of talking about their problems – *'…Changing production based on hygiene and product demand changes. Need to change the terms of trade with major customer.' (Farmer, AU);* mentioning their opportunities – *'Indirectly, a change in attitude among public around how they value security of food production and therefore role of farmers in providing that food.' (Farmer, NZ);* explaining their solutions – *'… some technology sales related meetings have relied on face to face, these have changed to online using Zoom or Office.' (Non-farmer, AU)*; or describing the future – *'Greater reliance on technology and changing workforces to designing automated processes rather than working in processes.' (Non-farmer, NZ)*.

The word frequency cloud generated by NVivo for the question about the problems encountered is given in Fig. 3 (see SM 8 for other questions) indicates the influence of COVID-19 on the agri-food systems. For respondents, the change can be negative, e.g. supply chain disruption or difficulties with labour, or positive, e.g. online innovations and new (or improved) markets. See SM8 for more detailed analyses.

4.3. Overview of interviewees

A summary of the interviews completed across the countries and sectors is given in SM9. Several of the interviews provided perspectives across multiple sectors so the 44 interviews yielded 60 sector by country perspectives. The interviewees were selected for their ability to provide a broad perspective of COVID-19 impacts on the sector and, in contrast to the survey (see SM5), were predominantly non-farmers with only 13% of the interviewees identified farming as one aspect of their role in the industry.

4.4. Impacts on agricultural exports

The sections below describe the impacts on agricultural exports to June 2020 based on information available in September 2020.

4.4.1. Australia

Australian agricultural trade continued largely unabated during the initial phase of the COVID-19 pandemic, falling by only $601 million compared to 2018–19. Rural Bank estimated the value of agricultural exports for the year ending June 2020 to be AU$50.1 billion compared to AU$48.5 billion in the previous year (Rural Bank, 2020). Notably, in the first half of 2020, Australian agricultural exports were 4% lower than the same period in 2019. The resilience shown in agricultural export performance is attributed to the essential nature of food as a commodity, and that most Australian agricultural trade relies on bulk shipping, which has been less disrupted than other forms of transport such as air freight (ABARES, 2020). However, sectors that were closely associated with food service and those reliant on airfreight, faced significant disruptions (Greenville et al., 2020).

Falling global commodity prices, reduced livestock exports and grain stock rebuild were expected to result in a 10% fall in the value of Australian agricultural exports to AU$43.5 billion in 2020–21. Exports of livestock commodities, including red meat, were forecast to fall by nearly 20% during 2020–21. This scenario is underpinned by altered consumer spending patterns in Australia and other major economies, reflecting a 'new normal', characterised by higher expenditure on food for home consumption, lower expenditure on restaurants and takeaway, and reduced spending on clothing. This situation was predicted to continue for some time and to be exacerbated and extended if future

Fig. 3. Word frequency of survey responses to the question about the main problems encountered. See SM8 for additional detail and the responses to the other three qualitative questions.

waves of infection and lockdowns were to occur (ABARES, 2020).

4.4.2. New Zealand

New Zealand's food and beverage sectors continued to produce and export through the lockdown as they were classified essential services. In contrast, fibre sectors such as forestry and wool were not allowed to operate during Level 4 restrictions (from 23rd March to 26th April 2020). Despite the logistical challenges and reduced production capacities caused by COVID-19 control measures, the primary sectors showed little slowdown compared to the beginning of the year. Export revenue from primary products for the year ending June 2020 exceeded revenue from the same period in the previous year (Statistics New Zealand, 2020e), with each of the dairy, meat and fruit industries exceeding export revenue from the year ending June 2019 (Statistics New Zealand, 2020f).

The forestry and seafood sectors were the most significantly exposed to the global impacts of COVID-19. The first drop in export revenues for the two sectors was felt from late January to March 2020 (Statistics New Zealand, 2020f). Revenue from forestry was already under pressure due to the extraordinary log supply from Europe. Subsequently, the Chinese New Year shutdown and lockdown resulted in a significant drop in log values due to both the stockpile of logs and low demand. The seafood industry drop occurred as the foodservice industry was closed in China. The second phase of sharp drops in export revenues for the forestry and seafood sectors occurred between late March and early May, aligning with both New Zealand's and other countries' responses to COVID-19. Forestry export revenue was originally on track to recover from the end of April 2020 (Statistics New Zealand, 2020f). While low log prices meant that harvesting from smaller plantations did not recommence, larger-scale businesses were able to capture benefits from lower shipping costs and the improved value of the New Zealand dollar.

There was a significant drop in venison export revenue from late January to June 2020, compared to the same period the previous year. Export revenue declined by 25% (Statistics New Zealand, 2020c) due to the closure of the restaurant and food service sectors in both Europe and the USA. Further, in the wake of the COVID-19 outbreak, China tightened its rules on the trade of wild meat and NZ farmed venison was included in this classification (Deer Industry New Zealand, 2020), despite New Zealand venison being from farmed sources. After pressure from the New Zealand deer industry, in June 2020 China relaxed some of its import rules and included New Zealand deer on the list of allowed imports (Deer Industry New Zealand, 2020).

4.5. Impact on agricultural sectors

All sectors except forestry and wool were classified as essential and permitted to operate during the highest shutdown levels in both countries. Nevertheless, they were affected by various combinations of reductions in domestic markets, throughput in off-farm processing, and availability of labour, inputs or support services. Table 1 summarises the main impacts for each sector group and SM9 summarises each of the major agricultural sectors in the two countries along with the major impacts.

4.6. Sectors were affected to a similar extent but by different avenues

Emphasising that the effects reported here are to June 2020, our analyses showed broadly similar, and relatively minor, economic effects across the surveyed industries. This contrasts with the effects emerging in South Asia (World Bank, 2020). Agricultural producers in Australia and New Zealand are well organised and business-oriented, and thus had the right structures and sufficient financial backing to manage through a pandemic. Product demand was maintained domestically due to income support, while export markets remained fairly constant (although some issues are noted below). The closure of restaurants and the food service sector did impact some sectors. Government support (Section 2.2, SM1 and SM2) assisted with maintaining freight capacity. Compared to some other countries, the agricultural businesses are relatively high-technology, which assisted with communications to find solutions and support. However, some sectors faced different challenges, as outlined in the following two themes.

Table 1
Summary of the key aspects of the impacts of COVID-19 by country and sector. "Horticulture" includes perennial horticulture and vegetable production. "Red meat" includes sheep, beef and venison. See SM9 for details. Sectors "permitted to operate" during the highest levels of shutdown included a requirement for distancing in the workplace and working from home, if possible, which reduced productivity and/or added complexity. 'PPE' refers to personal protective equipment.

Australia	New Zealand
Forestry (not permitted to operate)	
Not interviewed	Affected early by slowing of demand from the Chinese market; largely recovered by June 2020
Horticulture (permitted to operate; distancing slowed throughput in processing plants)	
Labour challenged without seasonal migrants; implemented new domestic marketing "Good Mood Food"; affected by reduced air freight; increase demand for 'high-health' products	Challenges with seasonal labour; difficulty accessing PPE; harvest successful with limited wastage; export channels remained open; vegetables experienced labour difficulties; reduced domestic demand
Wine (permitted to operate)	
Sector also affected by bushfires in late 2019 and had lowest harvest in a decade; expecting substantial business closures	Affected by lack of tourists & cellar door sales; seasonal migrants in-place before shutdown
Broadacre cropping (permitted to operate; processing relatively unaffected)	
Difficulties in obtaining some inputs such as agrichemicals and specialised equipment parts	Challenges getting equipment serviced; greater proportion of wheat production into higher-value flour for consumer usage
Red meat (permitted to operate; distancing slowed throughput in processing plants)	
On-farm operations relatively unaffected but there were disruptions in the processing chain; exports were down as a flow-on effect from previous year's drought but prices were high	On-farm operations relatively unaffected except shutdown overlapped with drought and unable to get sufficient animals off farm resulting in feed shortages; deer meat exports affected by reduction in restaurant market
Dairy (permitted to operate; distancing slowed throughput in processing plants)	
General conditions improved as industry recovered from drought; adversely affected by reduction in café/restaurant trade	Reduced ability to cull cows affected feed supplies; challenging operating environment for vets; exports maintained
Pork and chicken (permitted to operate)	
Affected by closure of café/restaurants where get higher value sales; labour productivity increased with smaller labour groups but non-stop operations	Pork badly affected by closure of domestic markets and café/restaurants; during shutdown; close to triggering animal welfare crisis; reduced throughput at processors

4.6.1. External or coincidental interactions

The effect of the timing of the pandemic with external influences negatively exacerbated its effect. Examples include large market fluctuations (forestry – see SM9 for details), bush fires (wine, cropping, beef in Australia) and drought (red meat, wool and dairy in New Zealand and Australia). In one case, the timing of the shutdown was fortunate (wine in New Zealand) as the harvest workforce was already in place. Had the shutdown started earlier, the industry would have struggled to process the grapes as there would have been insufficient labour in place.

4.6.2. Perishable or non-storable goods and the market (domestic or international) shut down

Industries such as red meat, forestry and processed dairy products have inherent flexibility or plasticity in that the system can slow down at one or more points in the production and processing chain (e.g. as standing trees, red meat kept on farm or stored chilled/frozen, grain crops harvested and then stored). Previous work (e.g. Rodriguez et al., 2014; Andrieu et al., 2015), has pointed out the advantages that such plasticity confers to production systems under stress and varying external drivers. Other industries are designed with a continuous steady flow through the production–processing–marketing chain and have minimal storage capacity, so have low plasticity and can be highly vulnerable to disruption. The pork and chicken industries are examples in this category. Disruption in these industries not only had an economic effect but also triggered potential animal welfare crises. Solutions to these disruptions required complex negotiation and innovative solutions (see SM9 and Section 5.1).

4.7. Some positive effects were noted

While most of the interviews focussed on problems and solutions, some positive effects were mentioned, including:

- the New Zealand pork sector noted that the steps towards solving their crisis had started more conversations with other sectors (e.g. red meat), which might serve all sectors well in the future;
- several industries noted that farmers became better and more accepting of virtual workshops, which would enable smoother communications in the future;
- the fertiliser and forestry industries noted an accelerated move to online/paperless transactions that will improve data sharing between organisations;
- a greater awareness in the non-farming community of both countries of the critical value of food and agriculture in maintaining social function;
- the forestry sector in New Zealand noted that they had increased productivity after the initial shutdown, which had been maintained;
- the reduction in travellers and farm visitors in both countries reduced biosecurity concerns in some industries;
- some staff earned higher wages through longer working hours; and
- there was a general interest in pushing technologies and automation in the primary industries to reduce the reliance on labour.

5. Synthesis and concluding remarks

5.1. Resilience in the face of adversity

Resilience, apart from being a buzzword in scientific and popular literature for most of the last century, reminds us of "*something that you find that you have after the fact, after you needed it…. or when you realise you did not have it.*" Coutu (2002). According to Adams, 1978, resilience, or the capacity to rebound from acute or chronic adversity, is related to longevity (or survival). Paraphrasing Gabriel Garcia Marquez, with 'life in the times of COVID-19', we are highly attuned to the concepts of resilience. In behavioural sciences and the study of behaviour in societies, resilience theories have identified three main characteristics of resilient people: their capacity to accept reality; a strong belief that they can succeed or improve; and a high degree of ingenuity or capacity to make do with whatever is at hand (Coutu, 2002). It seems that all three characteristics were evident in the response of the New Zealand and Australian agri-food sectors to the COVID-19 pandemic. It may also be that the history of no or low subsidisation of growers and farmers in both countries (Vitalis, 2007; Greenville, 2020) has already winnowed out those with lower financial resilience.

In Fig. 1, we hypothesised that for Australia and New Zealand agri-food systems, resilience in the times of COVID-19 would be driven by five critical subsystems: the production and processing system, the economic system, institutional activities, social and cultural interactions, and the environment. Our survey and interviews showed multiple sources of high resilience against the impacts of the COVID-19 and that may explain the relatively minor losses to date (June 2020). We note several points.

- Restrictions and new rules of engagement and interaction were adopted rapidly. People accepted a new reality and adapted to it.
- A strong 'can do' and cooperative – yet independent – spirit in the agricultural industries was a significant driver that minimised losses and uncertainties.
- The industry assimilated the many 'unmanageable disruptions', such as the loss or disruption to export markets and short supply of inputs. This created impetus for diversifying markets and strengthened business cases for value-adding and local manufacturing.
- The high level of ingenuity in the rural communities, both in Australia and New Zealand, was likely a key element of their resilience and capacity to overcome movement restrictions and the disruption of value chains.

Important lessons were learned, particularly on opportunities to increase the resilience of the sector to unprecedented change including:

- the importance of widespread access to reliable and fast internet and telecommunications;
- the value of labour-saving technologies like autonomous/remote-controlled vehicles and machinery;
- the need to upskill young people in rural areas and control or reverse the negative rural migration;
- the need to redevelop a technically efficient and modern national manufacturing sector to provide critical inputs (e.g. herbicides, fertilisers, seed production);
- the need to diversify export markets, value-adding and value chains;
- the need to improve business intelligence, flexibility or agility, and training;
- the need to plan for the 'unplannable' to deal with the next 'Black Swan'; and
- a renewed focus on human welfare – the need to provide mental health networks and other social services to enhance the ability of individuals to cope with unprecedented abrupt change.

In Fig. 1 we suggested multiple sources of resilience. It is useful to revisit this (Fig. 4) to contrast the resilience of two categories of industries within the agri-food system. Some industries have high inherent plasticity in that they can slow, pause or accelerate their production, processing and distribution system. They have capacity to accumulate product at some point in the production-processing-distribution system. For example, foresters can leave trees standing, red meat can manipulate supply from farm to processors via their meat schedule, and the cropping industry can store dried grain for extended periods. This contrasts with those industries that have low plasticity and are structured for a steady throughput (e.g. pork or chicken) and that have little capacity to store or accumulate product within the system.

Both types of industry, to June 2020, have proved resilient to the impacts of COVID-19 but they had varying vulnerabilities and achieved resilience through different combinations of mechanisms. The vulnerability of the industries with plasticity was through availability of inputs and market disruptions. Their resilience was achieved through strong economic resources, that their industry had the flexibility to work around some restrictions on inputs, and through using their social and cultural systems to identify and implement solutions. A low-plastic industry designed for a steady throughput, such as pork or poultry, had little inherent resilience in their production and processing system but this was offset by using higher levels of resilience in their institutional (e.g. negotiations with government) and social (e.g. agreement across

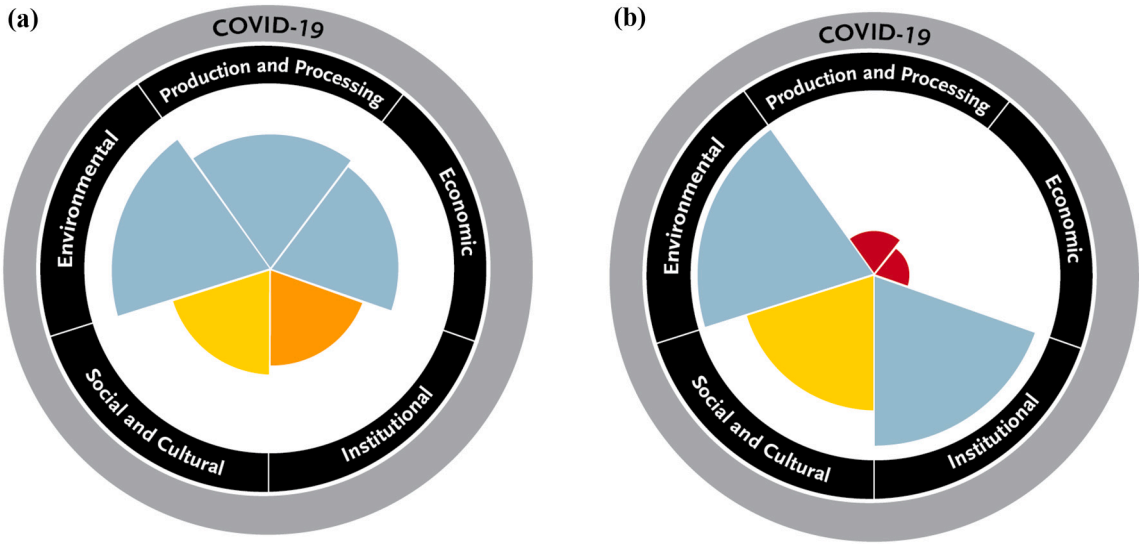

Fig. 4. Multidisciplinary resilience framework adapted from Fielke et al. (2018) configured for industries in which progress through the production and processing system can be interrupted by various means to give it plasticity (a; e.g. broadacre cropping) against those designed for a steady throughput with low plasticity (b; e.g. pork). The five resilience mechanisms from Fig. 1 are shown. The hotter the colour and the greater the size of the segment, the higher the degree of engagement of that mechanism. During this immediate phase (to June 2020) of response to COVID-19 both types of industries were resilient but via different mechanisms.

processors to cooperate) systems. Previous work (e.g. Dey et al., 2019; Darnhofer, 2021) has noted that a strong institutional dimension can at least partially offset weaknesses elsewhere to bolster industry resilience.

5.2. Possible longer-term impacts on agri-food systems

From the survey and interviews, we note several questions to follow up in a subsequent study.

- To what extent has the jump to, or interest in, higher technology methods (video conferencing, paperless transactions, labour-saving robotics) been maintained? Have there been any issues from, or implications for, data ownership?
- Have international markets rebounded? In the short-term, domestic markets have somewhat replaced international markets – will this change? Is the cost of airfreight still prohibitive?
- Has the shortening of supply chains, reluctance for just-in-time supply, and more direct marketing been maintained?
- Many of the industries have become dependent on seasonal migrant and backpacker labour for particular stages in their production year. Has that supply of labour returned? If not, how have the industries adapted? If seasonal migrant labour has not returned, what has been the effect on the communities that their labour used to support?
- In general, Australia and New Zealand export to high-value markets. What are the lingering effects of COVID-19 on those markets? Will there be a readjustment to demand from those markets as the economic effects of the pandemic grows? Has the pandemic caused or influenced structural changes in markets (e.g. a change to more local supply)?
- Both countries' economies rely on tourism. Several industries noted that cafés and restaurants were their higher-value markets. Has this market recovered? Much air freight is also on passenger flights. If the capacity has not rebounded, how have those industries reliant on airfreight adapted?
- Lamichhane and Reay-Jones (2021) suggested that the impact of the pandemic on inputs to farming systems (noted in our survey) should lead to future cropping systems that are more diversified with less reliance on synthetic inputs. Has this eventuated?
- For this first six months, the agri-food sectors have been relatively resilient. As the COVID-19 control measures extend, are these mechanisms holding?
- Meuwissen et al. (2019) and Darnhofer (2021) noted the important role of adaptability and transformability in the resilience of farming systems. In this immediate period (to June 2020) we have some evidence of some transformations in the way that the agri-food systems operate. Have these been maintained? If so how important have they been in conveying resilience?

5.3. Concluding remarks

In May 2020, Stephens et al. 2020 noted a variety of impacts of COVID-19 on agri-food systems worldwide. In general, the agri-food systems of Australia and New Zealand coped well during the initial shutdown. This is in contrast to the stronger effects noted in India (Balwinder-Singh et al., 2020) and Nepal (Adhikari et al., 2021). We suggest that the resilience emerged from a combination of:

- the industries having relatively high technology;
- being well connected/networked;
- having some experience of prior shocks;
- being lowly subsidised by their governments so those with low financial resilience had likely already exited the industry; and
- being well supported, primarily logistically, by their governments.

Indeed, the industries' international markets mostly held up well, as did the domestic market. We note that for some of the industries, particularly those that cannot readily slow their production and processing, success was brought about by the concerted efforts of people in many roles. Collaboration within and between industries and a 'make it work' attitude served many well.

The future of agri-food systems is always uncertain but with COVID-19, there may be more structural and technological changes in the next few years. A follow up study to understand these will be illuminating and will help to better understand the role of compensating resilience systems in overall robustness against external shocks.

CRediT author statement

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Declaration of Competing Interest

The authors declare that there is no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2020.103025.

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