The Economic Benefits of the New Zealand Food Safety Science and Research Centre

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Client Report prepared for the New Zealand Food Safety Science and Research Centre

May 2023

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Executive Summary

The New Zealand Food Safety Science and Research Centre (NZFSSRC or "the Centre") is a national, virtual scientific network of New Zealand's food safety researchers, hosted by Massey University and launched in 2016. The Centre synthesises input from industry, government, researchers and Māori to promote, coordinate and deliver food safety science and research for New Zealand. NZFSSRC is funded by government and industry.

In 2022, the NZFSSRC commissioned the Agribusiness and Economics Research Unit (AERU) at Lincoln University to quantify the value of the Centre's work and its impact more broadly in New Zealand.

This study builds on a literature review of the benefits of food safety undertaken by Guenther et al. (2022) as part of this research. Research methods included interviews with participants from food industry and a desktop analysis.

Three case studies for economic valuation of the Centre's involvement were constructed. These case studies do not capture all of the benefits of the NZFSSRC, but they are representative examples that indicate its substantial impact.

Case study findings by industry:

1. **Dairy industry**

- *Case Study: Avoiding costs from a hypothetical Cronobacter outbreak in New Zealand.*

  The existence of the NZFSSRC, as reasoned by an interview participant, helps prevent large food safety outbreaks such as the Cronobacter incident that occurred in the United States (US) in 2021/22. Calculations estimated a total cost saving through the work of the NZFSSRC of such an outbreak of NZ$691 million (based on a one-in-ten years occurrence). If the outbreak was in 5 years' time, then the current value of savings would be NZ$541 million and annual net present value savings of NZ$54 million.

- *Case Study: Avoiding dairy plant closure via Whole Genome Sequencing (WGS) arising from NZFSSRC research*.

  NZFSSRC WGS research allowed the isolation of a harmful pathogen found in a dairy processing plant. Only one dryer at the plant needed isolation. Based on this, the processing firm was able to simply remove one dryer from production at the plant, saving NZ$100,000 in costs associated with plant closure and testing.

- *Case Study*: *The prevention of a ban of whole milk powder (WMP) exports to the EU based on NZFSSRC advice to members of the New Zealand dairy sector on the likely shift in EU policy on maximum residue limits (MRLs) in cleaning agents.*

  NZFSSRC gave advice to dairy companies on EU law changes of the MRLs in cleaning agents in dairy processing plants. This prevented a ban of WMP exports to the EU with an estimated cost saving ranging between NZ$5 million and NZ$39 million assuming a 3 to 24 month transition period to a new cleaning agent for dairy processing plants.

2. **Kiwifruit industry**

- *Case Study: Impacts of NZFSSRC-led research on the potential transmission of COVID-19 via food or beverages including their packaging.*

  NZFSSRC research avoided an approximately 3 to 6-month export ban of kiwifruit into China. Calculations estimated a range of prevented economic cost of NZ$80 million (3 month export ban) to NZ$110 million (6 month export ban). In addition, this research also avoided the development of an unnecessary global (ISO) standard for food packaging. The calculations resulted in NZ$9 million annual cost savings from avoiding audit costs for **all** New Zealand food exporting companies. This value is significantly underestimated as it does not include any pre-audit costs for the companies or additional costs occurring during the audit process.

3. **Poultry industry**

- *Case Study: Impacts of the NZFSSRC-led longitudinal study on tracking Campylobacter in poultry flocks.*

  Calculations estimated that prevented costs from the Centre's research range from NZ$15 million to NZ$31 million per annum by avoiding an extension of the processing stage by 2 to 4 hours for 1,121 cases annually.

The total cost saving identified in this report amounts to NZ$164 million annually. This is compared to the annual budgeted operating costs for the NZFSSRC of NZ$2.5 million from government and industry.

The estimated benefits are extremely conservative. The analysis does not include, for example, the costs of legal action or brand damage to New Zealand companies resulting from a food safety incident. These indirect costs can be more severe than the direct costs of a food safety incident as they usually last longer. However, reputational and brand effects are almost impossible to measure.

Further benefits from the NZFSSRC emerged from the interviews. These are less tangible and difficult to quantify in monetary terms but significant to NZFSSRC industry members. These identified benefits significantly contribute to the prevention or reduction of costs from food safety outbreaks. The NZFSSRC:

- is a central point for food safety research and funding coordination. This prevents repetition of research while promoting shorter communication chains and faster response times. It also fosters access to and allocation of experts on particular food safety topics and creates research and new knowledge benefitting other companies and sectors.
- facilitates networking, relationship building and capability development through industry groups and taskforces.
- contributes to understanding the importance of food safety in the food system.
- offers scientific credibility and integrity as an independent research centre that produces high quality independent research.

Whole Genome Sequencing

A key research capability developed and facilitated by the NZFSSRC is WGS for pathogen detection and surveillance. The establishment of the NZFSSRC has accelerated the development of scientific expertise and the widespread use of WGS for food safety research in New Zealand. Almost all food industries have been involved in a collaborative research project with NZFSSRC involving WGS of pathogens. The main benefits of the technology are its potential to speed up analysis, its specificity and its high discriminatory power. Additionally, WGS allows for quick identification of outbreak sources, which means outbreak intervention at an earlier stage to decrease the associated health and economic costs.

Conclusion

The NZFSSRC creates value in providing and coordinating food safety research and networks for New Zealand through its unique relationship of government, industry, researchers and Māori. This relationship is key for generating positive outcomes for New Zealand food safety.

Chapter 1
Introduction

The New Zealand Food Safety Science and Research Centre (NZFSSRC or the Centre) was launched in 2016. The Centre, hosted by Massey University, is a national, virtual network of eight research organisations. It synthesises input from industry, government, researchers and Māori to promote, coordinate and deliver food safety science and research in New Zealand. NZFSSRC is funded by government and industry. The Centre's role in underpinning New Zealand's reputation for safe food is vitally important (IFC, 2021). The NZFSSRC team includes highly skilled professional scientists from a wide range of disciplines, providing coordinated advice to all stakeholders; industry, Māori, the public and government. Hence, the Centre creates economic and social value through coordinating and conducting food safety research. It also provides access to expertise in response to not only the everyday challenges of New Zealand food industries, but also the challenges created by pandemics, food recalls, extreme weather events and input into policy development.

NZFSSRC commissioned the Agribusiness and Economics Research Unit (AERU) at Lincoln University to help quantify the value of the Centre's work and the impact of this on New Zealand. This study builds on a literature review of the benefits of food safety undertaken by Guenther et al. (2022). AERU researchers interviewed senior people from key organisations in the New Zealand food industry to request background information and data on the impact of the Centre on their industry sector and the New Zealand economy. The AERU research team is grateful to all those who participated in this part of the research. The interviews were conducted online, facilitated by Distinguished Professor Caroline Saunders and Research Officers Meike Guenther and Timothy Driver. Notes made during the interviews (which were not recorded) are the basis for much of the material contained in this report. The information and data gained from the interviews were used for two purposes:

(1) to describe the benefits of the Centre to food safety in New Zealand; and

(2) to undertake an analysis of the economic contribution of the NZFSSRC.

The analysis is based on three representative cases studies. These studies do not cover the full NZFSSRC portfolio; they were selected because official data could be easily accessed for this report, supplemented with reviews of the relevant literature and access to other data sources. Consequently, the result is a partial analysis of the total benefits of the Centre, constrained by data availability. The estimated benefits are therefore conservative and underestimate the full impact.

This report is structured as follows. Chapter 2 presents findings from interviews with industry partners on the benefits of the Centre to food safety in New Zealand. Chapter 3 describes the selected case studies and their economic valuation. Chapter 4 outlines the benefits and barriers of WGS, which is one of the key research capabilities developed by the NZFSSRC. Chapter 5 is a brief conclusion.

Chapter 2
Contribution of NZFSSRC to Food Safety in New Zealand

The interviews with key stakeholders in the food sector identified several ways in which the NZFSSRC contributes significantly to food safety in New Zealand. Some of these benefits are difficult to quantify in monetary terms but are nevertheless significant in preventing or reducing the cost of food safety outbreaks for the country. This chapter focuses on four key pathways that deliver food safety benefits.

The NZFSSRC:

1. is a central point for food safety research and funding coordination;
2. facilitates networking and relationship building;
3. contributes to understanding the importance of food safety in the food system;
4. has scientific credibility and integrity as an independent research centre producing high quality research.

2.1 Central point for food safety research and funding coordination

Many interview participants commented on the value of having a central point of contact and coordination for New Zealand's food safety science and research activities. One participant highlighted *"…. having that source of knowledge and* ***a central point to go to is really helpful."*** Another participant stated,

> *If I would need to find all information by myself,* ***I would be years behind without the support*** *and I am able to get funding. It's not just the funding but knowing the experts that are picked are the best in New Zealand to do that piece of work. That provides confidence back to our leadership team and board, that we're not just throwing money away. We have our best people/subject matter experts working on these things*.

Benefits of this coordination role include: not repeating research; shorter communication chains and faster response times; access to and allocation of experts on particular food safety topics; and dissemination of knowledge to benefit other companies and sectors.

One participant explained that the NZFSSRC plays a significant role in three areas of food safety: (1) risk assessment; (2) risk management; and (3) risk communication.

First, in the risk assessment domain, prior to the establishment of the NZFSSRC, industry would approach food safety academics directly. Participants stated this process was costly and time-intensive, which did not help firms deal quickly with a food safety issue. Following the establishment of the NZFSSRC and its creation of programmes such as the Emerging Risk Identification System (ERIS), the ability of industry to identify food safety issues and assess the risk they pose to consumers/market access has greatly improved.

Second, a risk management example that was mentioned by an interview participant was that the NZFSSRC has been highly effective identifying possible food safety hazards such as pathogenic bacteria.

This also extends to other areas of supporting risk management. For example, the NZFSSRC has assisted its members to anticipate and adapt to changes in international legislation regarding cleaning compounds used in food processing plants, thus assisting in mitigating risks from legislative changes in export markets. One participant stated that *"for the food industry, proper risk management means the difference between keeping manufacturing going versus closing down, which has very big costs…"*, further stating that if the NZFSSRC were to cease operations, *"it will substantially reduce our ability to do risk management in New Zealand."*

Third, the NZFSSRC has been effective in risk communication. The NZFSSRC's timely literature review by Kingsbury (2022) on the transmission of COVID-19 via food and food packaging was published on its website, and updates were circulated to the network via e-mail. This review showed that COVID-19 is not transmissible through food or its packaging and helped to prevent the development of an unnecessary new international standard (see Section 3.2 for more detail). One participant stressed that *"within a week we could mobilise the NZFSSRC and see if they could put together an opinion on this and that we could put into ISO that there was no need for a test on the outside of packaging. This was a big win for the industry."* Respondents highlighted that this review was excellent and a good example of risk assessment.

2.1.1 Shorter communication chains, faster response time

The NZFSSRC allows more effective communication which results in a faster response time on food safety matters. Multiple participants stated this as a key benefit of the Centre, citing the immediate response from the NZFSSRC as being critical to responding to food safety issues. One participant stated, *"There is a bit of a fund that [the New Zealand food industry] can* ***immediately call up and get a report done*** *(an immediate response) …* ***Having the NZFSSRC being nimble is really important."***

Another participant stated, *"In the early days of COVID, with the information that came from NZFSSRC, we were able to give our customers reassurance that we weren't breathing COVID onto our product/packaging... That was* ***invaluable*** *– it hit the world pretty hard, but* ***we were able to still quickly send product out*** *and into China* ***by having the information so quickly available****."* Section 3.2 of this report discusses this further.

2.1.2 Access to and allocation of experts to food safety topics

The NZFSSRC facilitates access to, and allocation of, experts on particular food safety topics. NZFSSRC members have reported a range of benefits from this, including improving efficiency, the ability to respond quickly to an issue using specific expertise, and ease of mind knowing that the most suitable experts have been engaged.

One participant stated, *"If there wasn't a NZFSSRC, [we would] have to rely on people networks and people that we know, and maybe the research provider [we know] is potentially not the best to engage…Food safety crosses many research institutions and universities, so* ***a lot of people to choose from…"*** Another participant stated:

> *The main benefits I see in the NZFSSRC is having a contact point that coordinates the expertise and scientists. I used to call up and [they] would point me in the right direction. There are many people in the Centre that could help, or send me off to one of the scientists.*

This participant further stated that *"It's **really helpful** to go to the NZFSSRC as the **font of knowledge** on food safety in New Zealand."* Another participant pointed out that without the NZFSSRC they would need to connect with overseas providers, e.g. in Australia or the United States (US). This participant observed that Australian or US industries are well funded for their work, further stating, *"Now we have a New Zealand-based group who are **as good as the rest of the world** [at] running through this process."* Another participant stated, *"Having a group of experts sitting there to rely on, to give that independently, is **incredibly valuable**."*

Taken together, these statements indicate that NZFSSRC members value having access to experts on specific food safety issues, facilitated by the Centre.

2.1.3 Research and knowledge benefit other companies and sectors

NZFSSRC activities benefit a wide community of companies and sectors. When a piece of research is completed, as commissioned by an individual firm, the results of this research often become available to other companies and other sectors. This reduces duplication of research on a topic, which supports the whole New Zealand food industry to use its research resources effectively. Many participants in the interviews saw this as a key benefit of their participation in the NZFSSRC.

Participants stressed that even if one firm is responsible for a food safety incident, this often affects other firms in the same sector, particularly in the case of exports. For example, one participant reported that, during a food safety outbreak from another firm in the same sector, their customer services department received a significant increase of calls asking about the safety of their products. This participant stated:

> *We got calls **asking which [of our products] were involved**. Other firms don't have the money and resources that we do, so we try to make sure that we lead the way, then **others can jump onboard**. It does have an effect – if [the food safety issue] was worse than that, **it could destroy a whole segment**.*

This was observed in the 2013 WPC 80 (an ingredient in infant formula and other dairy products) incident when products from Fonterra were suspected of being contaminated with *Clostridium botulinum.* Other dairy firms experienced decreased sales due to the scare (Wood, 2013).

NZFSSRC research is cited as having significant benefits for the whole sector, creating an improved system of food safety management, and a recognition of the shared burden of responsibility for maintaining food safety. A participant suggested that any research conducted on water-based topics would be beneficial to all food industry members, since water is used in all New Zealand food industries.

Comments were made that access to some research is still restricted by some members or sectors. While participants stated that the culture of sharing food safety related information is improving in New Zealand, some participants remain reluctant to share their results due to issues such as commercial sensitivity. Nevertheless, the NZFSSRC has contributed positively to a culture change in New Zealand food safety, with participants now sharing high-level results with other firms within their sectors.

2.2 Networking and relationship building

A key benefit of the NZFSSRC is the increased capacity for networking, collaboration, and relationship building between sectors and food safety experts. The NZFSSRC facilitates several industry groups to provide members with access to critical and timely information, including the ability to communicate with food safety experts. Many industry participants commented favourably on the ability to network with other firms and experts on food safety issues because of their membership with NZFSSRC. For example, one participant stated:

> *It's certainly been value for money. The other part of it that is really hard to put a value around is **the networking you get from being part of the centre** and the involvement (it's **really hard to put a price on something like that**).*

Another participant indicated:

> *The industry does share a lot of information. In New Zealand, we actually encourage and organise to look and see if we can pick out bits that are working in one plant and apply them to another. That contribution is quite good.*

Participants commented favourably on groups facilitated by the NZFSSRC – specifically, the Emerging Risk Identification System (ERIS) Action Forum, the Industry Advisory Group (IAG), and sector-specific taskforces.

2.2.1 Industry groups

Emerging Risk Identification System (ERIS)

The NZFSSRC operates the Emerging Risk Identification System (ERIS) – a system for identifying and focusing scientific research to avoid or reduce the impact of future food safety risks. ERIS was established to guide the NZFSSRC's research priorities to specific areas based on the need to respond quickly to emerging food safety risks that could impact New Zealand producers. ERIS started originally in 2017, led by the Institute of Environmental Science and Research (ESR) with support from both New Zealand Food Safety (NZFS), part of the Ministry for Primary Industries (MPI), and the NZFSSRC (NZFSSRC, 2021a). The Centre publishes a monthly ERIS brief, which is publicly available and provides updates on potential emerging food safety issues (NZFSSRC, 2023a). ERIS was scheduled to run until April 2023, and at the time of writing this report is being considered for extension into 'ERIS 2.0', with the NZFSSRC stating that "*Feedback from our funders and networks is clear: ERIS needs to keep going"* (NZFSSRC, 2022a).

Many interview participants commented favourably on ERIS, stating that this system provides them with the means of detecting potential domestic and international food safety issues in advance, giving them time to respond to emerging threats. One participant stated:

> *One piece that's really relevant in the risk assessment domain, and New Zealand as a whole, is the Emerging Risk Identification System (ERIS). This is a system that leverages New Zealand's academia…they do horizon scanning… We've seen the emergence of risks in specific markets that are likely to move to New Zealand – then you've got three weeks to get your ducks in a row. **This is worth gold to us to have that kind of thing. ERIS is essential**. If this stops, it would be like shooting ourselves in both feet – **it would be an absolute disaster**.*

Another industry member stated:

> *[ERIS has] been* ***really useful.*** *The fact that there's a bunch of experts looking for and scanning emerging incidents overseas and potential threats that we need to search for and start to become aware of that could become an issue for New Zealand. I can't remember how much we need to pay for that, but* ***it's great****. If we didn't have the NZFSSC, I'd have to spend my time on this, or have that done, so we can stay abreast and ahead of the curve.*

Other interview participants indicated that ERIS has been *"incredibly helpful"* in achieving their food safety goals.

Industry Advisory Group (IAG)

Another opportunity for networking and collaboration facilitated by the NZFSSRC is the Industry Advisory Group (IAG). This involves approximately 35 representatives from different New Zealand food industries who meet quarterly to discuss sector-specific and cross-sectoral research needs. The group promotes information sharing around current and emerging issues and best practice in food safety. IAG has also been important to the development of ERIS. One participant stated, *"The Centre organises the Industry Advisory Group on food safety issues –* ***this is invaluable*** *for relationship building."*

New Zealand food industry taskforces

In addition to ERIS and the IAG, the NZFSSRC facilitates four New Zealand food industry taskforces; dairy, horticulture, poultry and seafood. Each taskforce comprises key industry members, government agency representatives and science experts (NZFSSRC, 2021b; 2022b). Interview participants commented favourably on the value of these taskforces. One participant stated that the industry taskforces are *"really useful"* since they are organised by sector. There is high trust in these taskforces, which are a useful forum to raise issues. Another participant who emphasised their usefulness stated that issues that are sector-wide (such as water-related issues) are often discussed within these taskforces (NZFSSRC, 2022b).

International policy linkages

Interview participants highlighted the importance of having a member invited to participate in the European Food Safety Authority's (EFSA's) Stakeholder Discussion Group meetings on Emerging Risks. EFSA is an independent agency providing advice on food safety matters in the European Union (EU). One member commented that EFSA "*leads the world*" in food safety regulation. Often, the policy direction set by EFSA is picked up by other markets around the world, including China. Another industry member commented that EFSA is "*six months ahead*". Information from this goes into the ERIS programme and helps to inform New Zealand food manufacturers of potential legislative changes in the EU and elsewhere. This gives New Zealand agencies a significant "head-start" in adjusting processes. This is explored in more detail in Section 3.1.2, which examines NZFSSRC's advice to the dairy industry on potential changes in cleaning-compound Maximum Residue Limits (MRLs) for EU market access for dairy exports.

2.3 NZFSSRC improves culture towards food safety

Many participants commented that NZFSSRC has helped to improve the culture in food safety in New Zealand. NZFSSRC activities have contributed, for example, to the development of a culture of improved sharing and coordination of information and knowledge. Hence, industries are more connected on food safety matters. As previously discussed, the recognition that every firm can suffer from a food safety outbreak caused by another firm in their industry has contributed to this sense of shared responsibility despite potential competition. Demonstrating this, one participant commented that *"The NZFSSRC has the ability to get people together – **we have been sharing results and high-level findings**."* Another participant stated that *"**the culture of the Centre is really good** and **fosters collaboration**."* Another participant stated that *"industries get together and we learn from each other, **sharing stuff** – **really helpful**."* One participant explained that the NZFSSRC has been a relatively safe forum to share information, adding that food industry members are *"more open than we've ever been with each other."* This participant also discussed the importance of shared goals among NZFSSRC members.

One participant emphasised that an improved culture towards food safety is important because of the reputational risk to the New Zealand brand from food safety outbreaks:

> *Small or big industry is irrelevant. **If small industries have problems or recalls, that market closes for all [of that sector]**. It's our whole industry. We managed to prevent several of those on a regular basis with SME industries.*

2.4 The Centre's strength of independence, scientific credibility and integrity

The NZFSSRC is an independent research centre with trusted scientific credibility. This is one of the key strengths of the Centre and is invaluable for industry, as confirmed in several interviews. One participant commented that "*As industry, we trial, we do lots of trials ourselves, but we have found that to get some kind of **acceptance or scientific rigour around them, we have used the NZFSSRC** – also to help design the trials we are doing. The NZFSSRC gives us perspective, and an alternative point of view, as well as robust discussion around this – it works reasonably well*."

Regularly, industry sectors approach the Centre for independent, scientific advice from the experts on a specific topic or issue. In personal communication, one participant stated that the '*Centre provides an **independent view of the food safety world'***; with another participant emphasising '***the Centre is unique** because of its independence*.'

The NZFSSRC regularly publishes resources and information to the food industry, government agencies and the general public on its website; via presentations at annual symposia; media articles; radio commentaries; seminar series; industry or community workshops; hui; and by acting as a source of information in response to questions through their web-based enquiry service (NZFSSRC, 2022b).

Further, the independence and scientific credibility of the Centre is important for communicating industry research results. Demonstrating this, one interview participant commented that "*For scientific credibility, it is important that the Centre is out front **– there's more credibility and its better received by the public and other stakeholders**."* Another interview participant highlighted that "*Communications from us are **not as strong as communications from the NZFSSRC**. It gives credibility*." Finally, one interview participant commented "*The Centre's scientific credibility is **very important to get public acceptance**. It is the rigor,* *transparency, and attention the Centre provides in designing, conducting, and reporting the research results*."

2.5 NZFSSRC provides research of high quality and depth

NZFSSRC research projects were described by interview participants as being of high quality and depth. This is achieved through a 'best teams' approach where researchers from different research organisations with relevant skills work together to solve an industry problem rather than competing against each other for funding. NZFSSRC researchers demonstrate appropriate breadth and depth to address issues. This multidisciplinary strength provides coordinated advice to clients, stakeholders, the public and industry (NZFSSRC, 2022b). Demonstrating this, one participant commented, "*The Centre provide(s) confidence that the science being delivered to industry* ***is of the highest quality****".* Another interview participant commented that "*We would have done it [the research] also if the Centre wouldn't be there but not* ***with so much rigour and depth***". In addition, there is confidence in the quality of the Centre's research, as one interview participant commented:

> *Review processes and the calibre of the science team/panels managed by the Centre provide confidence that the science being delivered to industry is of the highest quality and has been adequately peer-reviewed before release*.

2.6 Current funding model of the NZFSSRC

The current NZFSSRC funding model requires industry to commit 60 per cent funding for the research undertaken by the Centre. Hence, the research is predominantly applied and of direct relevance to specific food industries. However, several interviews highlighted a need for public good research because many food safety related issues and topics are relevant to multiple food sectors, so that good science is in the overall interest of industry and the New Zealand public.

The Centre notes that public good research is required in order to undertake research that is independent of enterprises in the industry and which extends across a wider range of areas critical to the health and wellbeing of New Zealanders. In particular, there is a need for research on emerging issues that may not yet be recognised by firms. An example is preparing food industries for new outbreaks and for impacts of environmental changes on food safety. Another critical area of public research is mātauranga Māori. One industry participant emphasised:

> *There are future issues that perhaps for industry are not quite on the radar screen yet. There may be a case for some more public good funding to front-of-industry research, e.g. potential new things that might hit.*

Chapter 3
Selected Case Studies for Economic Valuation

This chapter uses three selected case studies to present a conservative estimate of the economic contribution of the NZFSSRC. The three case studies come from three industries:

1. **Dairy industry**

   Case Study: Avoiding costs from a hypothetical Cronobacter outbreak in New Zealand

2. **Kiwifruit industry**

   Case Study: Impacts of NZFSSRC-led research on the potential transmission of COVID-19 via food or beverages including their packaging.

3. **Poultry industry**

   Case Study: Impacts of the NZFSSRC-led longitudinal study on tracking Campylobacter in poultry flocks.

These case studies do not cover the full range of benefits created by the NZFSSRC. One participant in the interviews, for example, came from a company in a food industry outside the three industries listed above. A recent product recall had cost the person's company around NZ$50,000 to NZ$60,000 and had caused market access issues and trade disruptions in export markets. The company has a project in collaboration with NZFSSRC to address the issue causing the disruption, which the participant believes will avoid these costs in the future. Rather than attempting to quantify what remains an uncertain future, this chapter's economic analysis focuses on example where there are reliable data sources validated by official sources, the scientific literature or the industry interviews. The analysis indicates that the benefits of NZFSSRC are substantial.

3.1 NZFSSRC contributions to the New Zealand dairy industry

Interviews with dairy industry members mentioned six areas where the NZFSSRC had or could save costs in the future. These include but are not limited to:

1. Prevention of large food safety outbreaks in New Zealand such as the 2021/22 US Cronobacter incident;
2. Assessment of nitrate exposure via water sources;
3. The use of WGS in dairy processing plants;
4. Understanding antimicrobial resistance in pathogens that are likely to enter dairy plants;
5. Response to COVID-19; and
6. The use of cleaning compounds in dairy processing plants.

This section begins with a detailed analysis of the prevention of a hypothetical Cronobacter outbreak in New Zealand, which was identified as a possibility with serious consequences for the country. This is followed by shorter analyses of the other areas.

3.1.1 Case Study: The 2021/22 US Cronobacter outbreak

In 2021/22 there was an outbreak of Cronobacter in US dairy industry. This section analyses the consequences of a similar outbreak in New Zealand if the New Zealand dairy industry did not have access to a food safety science and research agency such as the NZFSSRC. Interview participants from the dairy industry proposed this hypothetical outbreak as a suitable case study for economic valuation, especially because the US dairy industry does not have a centre based on a tripartite relationship of government, industry and researchers like the NZFSSRC.

Background

In February 2022, a major US manufacturer of infant formula products intended mostly for the US domestic market announced the potential presence of the bacterium *Cronobacter sakazakii* in a range of its infant formula products. This followed reports of the hospitalisation of infants who had been fed the US manufacturer's products. *Cronobacter sakazakii* (herein referred to as simply Cronobacter) is a bacterium that can be found in the natural environment, but in a food safety context is often found in dry food products, such as powdered infant formula or powdered milk. Serious health risks are associated with Cronobacter infection of babies younger than 2 months old, of older people and of the immuno-compromised. Cronobacter can produce life-threatening symptoms, as well as cause serious chronic health conditions (CDC, 2022b).

Studies have examined the determinants of Cronobacter infections in humans. For example, Strysko et al. (2020) examined the source of Cronobacter infections in infants between 1961 and 2018, finding that 79 per cent had consumed powdered infant formula prior to infection, with 30 per cent of these infections linked to opened infant formula containers. Furthermore, Jason (2012) examined rates of Cronobacter infection in infants between 1958 and 2010, finding that 90 per cent of Cronobacter infected infants had received either powdered infant formula or human milk fortifier.

In September 2021, the US Food and Drug Administration (FDA) carried out a routine visit to a factory in Sturgis, Michigan, where it found evidence in company records that Cronobacter had been present at the plant. Indeed, the company had found evidence of Cronobacter at least five times in two years. The company was not required to notify the FDA, and didn't; instead, it responded internally. FDA inspectors found faults with health and safety procedures at the plant, as well as damage to equipment that could encourage the proliferation of pathogens. On the first day of their five-day inspection, the FDA received news that an infant who had consumed one of the products produced at the plant had been hospitalised with a Cronobacter infection. While the company was notified by the FDA directly, this information was not passed onto the FDA inspectors, with no immediate repercussions for the company beyond this notification (Berfield & Edney, 2022; CDC, 2022a; Forbes, 2022; Perrone, 2022).

In October 2021, a whistle blower report was forwarded to the FDA by a former employee suggesting that plant management emphasised productivity over health and safety, including various violations of health and safety principles. Following this, three more infants were hospitalised with Cronobacter infections, and two infants died. A further FDA inspection in January 2022 found evidence of the presence of five different strains of Cronobacter at the plant. As a result, the company voluntarily recalled approximately 70 million cans of potentially affected infant formula products from the US market, and the plant temporarily ceased production on 17 February 2022 (Berfield & Edney, 2022; CDC, 2022a; Forbes, 2022; Perrone, 2022).

At least three class action lawsuits were filed against the company on behalf of affected parties, including the families of victims and shareholders (CAR, 2022; Portnoy Law, 2022; Silva, 2022; White, 2022). Costly legal action is a common feature of food safety incidents (Guenther et al., 2022). In the US, class action suits often result in significant costs for the responsible parties. The top 20 monetary settlements from class action suits in the US in 2022 ranged from US$453 million to US$7.4 billion (Duane Morris, 2023). Our analysis does not include these costs, but nevertheless the implications of such an outbreak would be significant.

We asked participants in the dairy industry how likely would it be - in the absence of NZFSSRC - for a food safety event similar to the 2021/22 US Cronobacter outbreak. The response is that once a decade would be a realistic possibility. We have estimated the economic and social costs based on that assumption.

Economic costs

Lost revenue

In the US Cronobacter outbreak, the plant under investigation ceased production activities for 136 days, between 15 February and 1 July 2022. Following 1 July 2022, the plant resumed production activities under strict FDA guidance to assist in resupplying the US infant formula market during a shortage (Sealy and Hassan, 2022).

In New Zealand, milk processing occurs throughout the season of approximately 270 days each year (Back & Sneddon, 2023). Large dairy processors have the capability to speed up or slow down the processing of milk powders (Fonterra, 2015). During the 2017/18 and 2018/19 milking seasons, for example, Fonterra's Lichfield plant operated for half of each season, due to strategic business decisions about the types and quantity of products required for international export markets.

Consequently, our scenario assumes that the outbreak occurs in a New Zealand dairy production plant that is running 24/7 for only half of the season; that is, for 135 days. This is a conservative approach, since plants can operate throughout the entire season, but it means our scenario closely matches the experience of the plant in the 2021/22 US Cronobacter outbreak, which was closed for 136 days.

New Zealand's dairy firms operate a number of milk processing plants to process liquid milk into milk powders, mostly for export. Each plant has different processing capabilities, depending on the plant's infrastructure and equipment. Fonterra's Edendale plant, for example, operates four milk dryers (Dairy Exporter, 2022). The largest and newest dryer at the Edendale facility (ED4) is capable of processing 30 tonnes of milk powder per hour (Dairy Exporter, 2022). Three such units are operated by Fonterra at different sites across New Zealand.

Thus, our scenario assumes that only one dryer is affected by the outbreak, and that this dryer would otherwise process a rate of 30 tonnes per hour. It should be noted that this is likely to be an underestimate of the potential effects of a New Zealand dairy food safety incident on production, as it is highly likely that all production at a plant would cease until the source of the outbreak was determined and controlled.

This assumes that the source of an outbreak can be directly linked to a specific production facility, using WGS which is promoted, facilitated and developed by the Centre.

To calculate lost revenue, it is assumed that all WMP produced in the affected dryer would be either removed from the market or destroyed.

The value of a tonne of WMP in this scenario is based on Fonterra's reported average market price per tonne during the 2022 season of US$4,019 (NZ$6,342) per tonne (Fonterra, 2022). This is again a conservate estimate, since different New Zealand dairy companies earn different amounts of revenue per kilogram of milk solids, some of which are considerably higher than this figure (TDB Advisory, 2020).

Based on the assumptions described above, the economic cost of a New Zealand dairy food safety outbreak is the loss of value from one dryer that would otherwise process whole milk powder at a rate of 30 tonnes per day, operating non-stop (24 hours a day, 7 days a week), ceasing production for 136 days. The revenue loss in this scenario is calculated by multiplying three items:

- The price per tonne;
- The number of tonnes of lost production per day; and
- The number of days of ceased production.

NZ$6,342 per tonne x 720 tonnes per day x 136 days = NZ$621 million in lost revenue

For comparison, the US company reported an estimated revenue loss of approximately US$170 million (NZ$268 million) between the first quarter of 2021 and the first quarter of 2022 (Forbes, 2022). Block (2022) suggested the total expected losses from the US company's recall were in the order of US$325 million (NZ$513 million). Lee (2022) suggested an even greater reduction in the company's nutritional business revenue in the order of US$450 million (NZ$700 million). Thus, this estimate of more than NZ$600 million appears plausible.

Other potential economic costs

There are other potential economic costs not considered here. As discussed in Guenther et al. (2022), economic costs associated with foodborne illness can include, but are not limited to: medical treatment coverage by responsible firms; regulatory compliance costs; traceability costs; product recalls; discarding potentially contaminated products; plant closure and cleaning; product liability; regulatory and legal response; insurance premiums; trade impacts; marketing and advertising (to restore reputation); and prolonged effects on the market due to reputation damages.

While some of these costs could be estimated with suitable assumptions, it can be difficult to estimate the more intangible costs that can be long-lasting and impact on a firms' social license to operate.

Some research has examined the potential reputational impact of the 2021/22 US Cronobacter outbreak. Jung et al. (2023) stated that the reputational risk was not isolated to the US domestic market, but also to export markets, specifically the 37 countries to which a limited amount of potentially compromised products were sent and subsequently recalled (FDA, 2022). Interviews with New Zealand dairy industry members indicated a potential cost of reputational damage of more than NZ$2 billion from the outbreak.

Other costs following a food safety incident include legal actions, as stated above. These can be significant as shown by Fonterra's pay-out to Danone of €105 million (NZ$183 million) based on the WPC80 incident. For this study, these have not been estimated.

In the 2021/22 US Cronobacter outbreak, multiple class action suits were filed, and criminal investigations brought against the firm by the US Department of Justice into their production processes (Bogage et al., 2023; Portnoy Law, 2022; Silva, 2022; White, 2022). Other possible economic impacts include: costs associated with addressing the US infant formula shortage (e.g. the temporary removal of tariffs, costs associated with Operation Formula Fly, and similar); costs of compliance with FDA processes; the cost of testing and plant cleaning; traceability and retrieval costs; and many others (NZFAT, 2022).

The exclusion of these additional outlays further indicates that the above estimate of economic costs for a similar outbreak in New Zealand is conservative.

Social costs

Mortality and quality of life

As discussed in Guenther et al. (2022), the social costs of foodborne illness typically include mortality, impacts on quality of life, cost of treatment and productivity loss. The first three aspects – mortality, quality of life, and treatment cost – can be proxied in a single value based on the assumptions in our scenario. Minor et al. (2015) undertook an economic analysis of the costs of Cronobacter in the United States based on 2013 prices. The analysis covered the monetised costs of hospitalisation, premature death (valued using the discounted *value of a statistical life*, VSL) and loss of *quality-adjusted life days* (QALD), which is easily adjusted to *quality-adjusted life years* (QALY).[1] The estimated impact was 4,023 QALD per case, representing a total monetary loss of approximately US$7 million per case.

The Center for Disease Control and Prevention (CDC, 2022a) recorded 2 deaths and 5 hospitalisations from the 2021/22 US Cronobacter outbreak. As the cost of mortality was incorporated into the estimate published by Minor et al. (2015), our analysis in this section concentrates on the social costs if a similar outbreak in New Zealand produced 5 hospitalisations. Monetary values from the US estimates were adjusted for inflation to 2022 values using an approximate cumulative inflation rate of 25.6 per cent between 2013 and 2022, and then translated into New Zealand dollars using the exchange rate.

Based on the above, estimates of the total approximate social costs (including mortality, quality of life, and treatment costs) for the 2021/22 US Cronobacter outbreak are shown in Table 3-1. Based on CDC (2022a) and Minor et al. (2015), estimates at the 5 per cent and 95 per cent confidence interval are also presented here. The table shows that the mean loss associated from social costs from the 2021/22 US Cronobacter outbreak totalled US$44 million, ranging between US$32.6 million and US$56.1 million. This included an approximate average 55.11 QALYs, ranging between 30.39 and 81.22 QALYs.

Assuming that the cost of Cronobacter would be relatively the same in a New Zealand context, Table 3-1 also presents the approximate social costs of a potential Cronobacter incident in New Zealand (converted

[1] Quality-Adjusted Life Years (QALYs) is a non-monetary metric used to estimate the impact of adverse health events on both the quantity of life years, as well as the quality of life experienced during those years, by those directly affected by food safety incidents, usually due to the onset of disability of premature death. One QALY represents one year of perfect health experienced (Buzby & Roberts, 2009; Focker & Fels-Klerx, 2020).

from US dollars using the average 2022 exchange rate of 1.578) (IRS, 2023). This estimates the mean social cost of a similar outbreak in New Zealand as NZ$69.5 million.

Table 3-1: Total approximate social costs (mortality, quality of life, and treatment costs) associated with the 2021/22 US Cronobacter outbreak, inflation-adjusted 2022 values.

	Mean	5% CI	95% CI
QALD loss (total)	20,116	11,091	29,645
QALY loss (total)	55.1	30.4	81.2
Monetary loss (total USD)	$44,046,520	$32,587,014	$56,143,426
Monetary loss (total NZD)	$69,505,408	$51,422,308	$88,594,326

Note: Monetary values shown are inflation-adjusted 2022 values, based on a US dollar inflation rate of 25.6 per cent between 2013 and 2022.
Source: CDC, 2022a; IRS, 2023; Minor et al., 2015; authors' own calculations.

The number of deaths and their associated costs reported here are conservative estimates. Incidence rates of foodborne illnesses in the general population are likely to be higher than those officially reported, as people may not come forward to be tested or treated (Sundstrom, 2018). In addition, the FDA investigated reports that as many as nine children had died following the consumption of baby formula produced at the affected plant since early 2021. However, these have not been included in the officially reported statistics (CDC, 2022a; Reiley, 2022). Furthermore, the baseline estimates derived from Minor et al. (2015) are taken from averages across the US population. Given that the patients in these cases were infants, the US population figure would not accurately represent the total QALYs involved per case, and the final number is likely to be an underestimate as a result as "*the magnitude of the VSL is a decreasing function of age*" (Viscusi & Aldy, 2003).

Other potential social costs

There are other potential social costs not considered here. Social costs associated with foodborne illness can include, but are not limited to: additional medical costs, including time associated with treatment and travel; psychological costs; and income or productivity costs for caregivers (Buzby & Roberts, 2009). In this case, it is difficult to estimate the value of other potential social costs due to their largely intangible nature. However, some research has examined the qualitative social impacts of this outbreak, particularly in relation to the US infant formula shortage, including adverse impacts on mothers' mental and emotional health, and increased intangible costs (e.g. time at stores, using technology, learning about feeding practices); see Abrams & Duggan (2022), Imboden et al. (2022), Kalaitzandonakes et al. (2023), Samuel et al. (2022) and Sylvestsky et al. (2022).

Total costs

Table 3-2 combines the social and economic costs of this scenario, which amounts to approximately NZ$691 million. As discussed above, this is likely to be an underestimate due to the factors that have been omitted.

Table 3-2: Total costs – New Zealand dairy industry food safety outbreak.

	Cost (NZ$ millions)
Social Costs	$69.5
Economic Costs	$621.0
Total Costs	**$690.5**

Source: Authors' own calculations, 2023.

These total costs of a potential outbreak are significant. As stated earlier, industry participants consider these outbreaks could occur once in a decade. Taking the midpoint, assume it occurs in 5 years. Using the Treasury's (2022a) recommended discount rate of 5 per cent, the present value of this cost saving over the decade is NZ$541 million. Dividing this by the 10 years, the annualised cost saving to industry of the Centre is NZ$54.1 million.

3.1.2 Other stories: New Zealand dairy

Interviews with participants from the New Zealand dairy industry revealed other potential cost savings through the NZFSSRC.

Impacts of potential nitrate exposure

In recent years, concerns regarding the potential negative health impacts of human exposure to nitrates have emerged. Nitrates are produced via agricultural activities. These compounds arise from animal wastes, as well as the use of synthetic nitrogen-based fertilisers (PMCSA, 2022). The New Zealand dairy industry has faced criticism for their nitrate management practices from production and processing activities, with concerns that nitrates could enter drinking water supplies and produce negative health impacts from nitrate exposure via consumption (Hancock, 13 Feb 2021; MacDuff, 2022). These concerns are important from a public health perspective, as some studies suggest a link between human exposure to nitrates and the development of health issues such as the development of colorectal cancer and methemoglobinemia (otherwise known as Blue Baby Syndrome) (PMCSA, 2022).

To determine the validity of the risk of nitrate exposure through human consumption of contaminated drinking water, the industry commissioned the NZFSSRC to examine the possible impacts of exposure to nitrates. This research was carried out by ESR (Cressey & Cridge, 2021) and involved an extensive desktop study to determine the rate of nitrate exposure in human populations via drinking water sources versus other dietary sources (e.g. food consumption). The authors found that approximately 9.1 per cent of daily nitrate exposure in New Zealand occurred via water sources, with most nitrate exposure occurring as a result of food consumption. The paper concluded that the link between nitrate exposure and colorectal cancer is unproven, with mixed evidence in the literature.

In particular, the authors discussed one study that is often cited to demonstrate this link (Schullehner et al., 2018), showing multiple methodological and technical issues that could undermine the integrity of its findings (NZFSSRC, N.D.). This work has been peer-reviewed and accepted for publication in a scientific journal (Cressey & Cridge, 2022). In addition, Bowel Cancer New Zealand (2021) stated that exposure to nitrates in drinking water is highly unlikely to increase the risk of bowel cancer in New Zealand (BCNZ, 2021).

Whole Genome Sequencing and plant expenditure

The facilitation of the use of WGS for the detection and mitigation of potential pathogens in dairy processing plants has been a key focus for the NZFSSRC. The Centre's work in this area has led to the establishment of WGS processes being routinely employed by large New Zealand dairy firms. NZFSSRC expertise is used to upskill staff, providing considerable value in food safety practices, as well as mitigating potential costs. For example, one dairy processor stated that they detected a potential incidence of a harmful pathogen in one of their milk processing plants. This would normally require the processor to shut down the plant until the pathogen could be isolated and removed. Instead, the processor arranged for NZFSSRC WGS research to be carried out, which showed that the pathogen was limited to one dryer at the plant. Based on this, the processor was able to simply remove one dryer from production at the plant, thereby saving approximately NZ$100,000 in costs associated with plant closure and testing. Based on the findings from interviews, this is an example of the kind of costs that are frequently saved by the intervention of the NZFSSRC. The Centre's involvement with WGS is discussed in further detail in Chapter 4 of this report.

Antimicrobial resistance

Another example is NZFSSRC work investigating possible antimicrobial-resistant bacteria emerging on New Zealand dairy farms, including those that could be resistant to the pasteurisation process. Specifically, there have been concerns regarding the potential emergence of strains of *Escherichia coli* resistant to pasteurisation. These could present potential food safety risks if they contaminated dairy products intended for human consumption. If the antimicrobial resistant *E. coli* is present, a dairy processing plant would be required to cease production to clean and reset the plant for production. In response to their concerns, industry commissioned the NZFSSRC to determine the extent of antimicrobial resistance in *E. coli* strains from farms supplying the affected dairy processor. Results showed that approximately 3.7 per cent of the isolates showed signs of resistance to at least one cleaning agent, with a slightly higher rate of antimicrobial resistance shown by strains recovered from farms with conventional husbandry practices compared to organic farm practices (Amoafo et al., 2022).

Interviews with the affected New Zealand dairy firm showed this research effectively allowed processors to mitigate concerns regarding antimicrobial resistance that could otherwise affect the continuation of their operations. Furthermore, the NZFSSRC also contributed to a literature review examining antimicrobial resistance in food in Australia and New Zealand, including the New Zealand dairy industry. This review showed that the literature indicated very low rates of antimicrobial resistance in New Zealand dairy activities (AGDH, 2018). This work presents a positive contribution from the NZFSSRC to the New Zealand economy in preventing production losses through plant closure.

Cleaning compounds

A further example of the benefits derived from NZFSSRC advice was reported by participants whose products are exported to Europe and regulated under European Union (EU) laws. The Centre identified that the EU were changing the MRLs for chemical compounds typically used as cleaning agents in dairy processing plants. In 2020, the European Commission (EC) amended Regulation (EC) 396/2005 to reduce the total MRLs of chlorates in food products (Regulation (EC) 2020/749) (EC, 2020). Chlorates are a group of chemical compounds that result from the use of chlorine-based disinfectants in food processing processes. Residues of chlorates in food products are considered by the European Food Safety Authority (EFSA) to have negative impacts on human health through long-term exposure (EFSA, 2015a; 2015b). In this case, the NZFSSRC was able to provide advice on a change in EU policy directions to industry and give advanced warning of the required changes to New Zealand dairy processing to meet market access requirements. In personal communications with a New Zealand dairy firm, it was stated that without NZFSSRC intervention they would have been required to "stop manufacturing and stop exports to Europe" which would potentially mean "*months' to years' worth of lost exports*" to the EU.

Maintaining market access

New Zealand exports butter, whey, milk powders, buttermilk and cheese products to the EU, with dairy exports to the EU valued at NZ$306 million in 2022. This was an increase of 53 per cent from its value in 2015 (StatsNZ, 2023a). In addition, the value of New Zealand's dairy exports is expected to increase in the future, with negotiations towards a New Zealand-European Union Free Trade Agreement (FTA) completed in June 2022 (with its ratification due in 2024). The FTA will include provisions for increases in export volume quotas to the EU, and the removal or reduction of tariffs on some agricultural products (Beehive, 2022; NZFAT, 2022). In particular, the total estimated benefit of export revenue from dairy products (butter, cheese, and milk powders) from fulfilling quota volumes as outlined in the EU-NZ FTA could approach approximately NZ$518 million (NZFAT, 2022).

In personal communications with a New Zealand dairy firm, it was suggested that the change in MRLs of chlorates would have affected predominantly whole milk powder (WMP) exports to the EU. Hence, only the value of WMP exports from that one dairy company is considered here to estimate the potential economic impact of NZFSSRC's advice. This advice prevented a ban of WMP exports into the EU. The dairy company has a market share of 81 per cent (TDB Advisory, 2020).

As a change in EU legislation would present months to years' worth of lost New Zealand WMP exports from that dairy company, a range of time-based scenarios are presented in Table 3-3, ranging between three months and two years. This shows that even at the lowest estimate (three months), the potential cost to one New Zealand dairy company from adjusting practices to fit EU market access requirements is estimated to be NZ$4.8 million, with a range of estimated costs between approximately NZ$4.8 million and NZ$38.6 million, depending on the time length of the export ban.

Table 3-3: Cost of lost value of WMP exports to the European Union (EU27) from changing market access related to cleaning compounds used in processing (for one New Zealand dairy firm).

Time (Months)	Value of Lost WMP Products NZ$ million
3	$4.83
6	$9.66
9	$14.49
12	$19.32
15	$24.15
18	$28.98
21	$33.81
24	$38.64

Source: StatsNZ, 2023a; Authors' own calculations, 2023.

These estimates are conservative because it is likely that required changes in cleaning compounds used in the plant would affect other dairy products as well, suggesting that the total cost could be higher than reported here. The estimated value of lost total dairy exports to the EU could be as high as NZ$62 million, assuming a 3 month transition period for that individual company.

COVID-19

The NZFSSRC contributed towards the New Zealand dairy sector's efforts to mitigate the negative impacts of COVID-19 on their operations. As this situation is discussed in detail in Section 3-2, it will not be explored further here. In summary, during the onset of the COVID-19 pandemic, Chinese authorities were particularly concerned about the possibility of the transmission of COVID-19 via imported food products and their packaging. Consequently, China sought to implement measures including an ISO standard[2] for the detection of COVID-19 on packaging. If implemented, this would have generated significant costs for food producers, processors and exporters nationally and internationally. However, the NZFSSRC was quickly able to coordinate research showing a lack of evidence that food or food packaging can effectively transmit COVID-19, thereby preventing the implementation of an unnecessary ISO standard, and its associated impacts on the New Zealand dairy industry and the whole food industry (Kingsbury, 2022).

3.1.3 Summary

This section has described potential cost savings to the New Zealand dairy sector that could be attributed to the intervention of the NZFSSRC in response to potential food safety incidents.

[2] ISO (International Organization for Standardization) is an independent, non-governmental, international organization that develops standards to ensure the quality, safety, and efficiency of products, services, and systems.

Table 3-4 shows a summary of the estimated total costs of each of the cases, including the potential cost of a similar outbreak to the 2021/22 US Cronobacter outbreak, dryer replacement via WGS methods, and response to changes in EU regulations regarding cleaning compound use. Across the three cases, a total cost saving of NZ$59 million per year is estimated.

Table 3-4: Summary of estimated annual cost savings generated to the New Zealand dairy sector attributed to NZFSSRC intervention, lowest estimates (NZ$ million).

Cases	Annual Costs *NZ$ million*
NZ Cronobacter Outbreak (5yr)	54.1
Dryer Replacement	0.1*
EU Cleaning Compound MRLs	4.8*
TOTAL	**59.0**

Note: * These are one-off events.

The estimated cost savings in Table 3-4 are conservative in each case. As described above, many costs associated with these cases are difficult to estimate, and thus have not been included in this analysis. This was also stated by Guenther et al. (2022), whereby many of the costs associated with food safety incidents cannot be accurately estimated, as either these costs are not frequently measured; or accurate or reliable data are not available. In addition, the costs presented in Table 3-4 show the lower estimates in all cases presented in this section.

Beyond this, the potential costs of reputational risk, while difficult to accurately estimate, could be more significant than the social and economic costs estimated above. Members stated that the costs associated with lost reputation caused by a food safety incident could exceed double the estimated social and economic costs of an outbreak, and the loss of consumer trust associated with this could be difficult to repair. Nevertheless, even without quantifying these considerations, the analysis of this section demonstrates that the saved costs attributed to NZFSSRC's work with the New Zealand dairy industry are significant. Their work in preserving the New Zealand dairy industry's international reputation could be critical to ongoing economic success for New Zealand exports.

3.2 NZFSSRC contributions to the kiwifruit sector in New Zealand

This section describes the Centre's contributions to the New Zealand economy as a result of their involvement with the kiwifruit industry in assessing and preventing food safety related incidents, domestically and internationally. For this economic evaluation, a case study is developed to estimate the benefit from the Centre's research on the 'possibility of transmission of COVID-19 via food or beverages including their packaging' (Kingsbury, 2022) for the kiwifruit industry and the whole New Zealand food sector.

3.2.1 Food safety issues in the New Zealand kiwifruit industry

The kiwifruit industry is the biggest sector in New Zealand's horticultural industry. At 40 per cent by value, kiwifruit was the highest value horticultural export crop in 2021, with 622,550 tonnes valued at NZ$2.7 billion, exported to 54 countries: Continental Europe NZ$796 million, China NZ$648 million, Japan NZ$559 million, Korea NZ$189 million, Taiwan NZ$130 million (Fresh Facts, 2021). Zespri International Limited is the world's largest marketer of kiwifruit, exporting into more than 50 countries and managing 30 per cent of global volume (Zespri.com, 2023).

In this report, the case study relating to the kiwifruit sector focusses on *Listeria monocytogenes*, which causes listeriosis. *Listeria monocytogenes* may either occur in an invasive or non-invasive form. In the latter, infection remains confined to the digestive system and manifests as gastroenteritis with flu-like symptoms. Little is known about the non-invasive form as it is non-notifiable, except when outbreaks occasionally occur (Gadiel, 2010; Gilbert et al., 2009). Listeriosis is a serious disease associated with high risks of mortality. Gadiel (2010) estimated that listeriosis costs were NZ$15 million annually in New Zealand, representing 11 per cent of total costs from six foodborne diseases in 2009. Gadiel (2010) did not identify the causes of these listeriosis cases. However, there is no known food safety outbreak from New Zealand kiwifruit in domestic or overseas markets. Despite low case numbers, listeriosis has a high per-case-cost (approx. NZ$778,188 per case) which reflects its potential for serious complications and a high risk of premature death (Gadiel, 2010).

There is a standard in New Zealand and the US that requires all ready-to-eat foods to meet a zero tolerance for Listeria (NZFS, 2017a; FDA, 2020). Hence, this is important to ensure market access for New Zealand exports.

3.2.2 Role of NZFSSRC to the kiwifruit industry

The Centre plays an important role for the New Zealand kiwifruit industry, predominantly through supporting and facilitating the funding of research aimed at reducing risks of food safety outbreaks. The Centre has completed a range of projects for the kiwifruit industry including risk ranking, water quality, microbiome assessment, possible contamination studies, shelf life, storage and traceability. Some of the many NZFSSRC projects with the kiwifruit industry are described below.

Listeria

In 2019, the Centre provided an understanding of the origin, entry points and dissemination of Listeria in production environments. Through this project, the NZFSSRC developed a robust approach to determine the potential sources and entry points of contamination at food production/processing facilities using new technologies. This approach helped the industry to reach growth targets and maintain market access by ensuring food safety. The research highlighted perceived potential drawbacks that food companies and regulatory authorities face and how these may be mitigated (NZFSSRC, 2019a).

NZFSSRC's and ESR's Listeria WGS database (more detail in Chapter 4) is a valuable resource for the kiwifruit industry in determining the relationships between current and previous Listeria cases. One project using WGS for the '*Identification of sources of contamination from kiwifruit orchards*' provided significant value to the industry. From personal communications with industry, it was highlighted that this project revealed the widespread occurrence of the pathogen which had not previously been obvious to the industry.

Typhoid

After typhoid cases in workers in packhouses occurred in 2015 and 2017, the Centre was commissioned by industry to undertake a literature review on *'The spread of typhoid fever to food'*. The two incidents cost the industry more than NZ$2 million combined. These costs included fruit disposal, longer storage time and delayed exports. The NZFSSRC research supported the development of incident protocols and an infographic for orchards and packhouses. In personal communication with the industry, it was pointed out that '*if we had it [protocols and infographic] before our typhoid outbreaks, it could have saved costs*'. This research helped the industry to prevent future incidents from typhoid fever and to prevent costs associated with these incidents. From this example, the author estimated that the Centre's research is preventing costs of approximately NZ$1 million annually by avoiding a food safety outbreak from the possible transmission of human diseases onto kiwifruit.

Risk ranking

Further, the Centre completed a project that produced a risk ranking of food safety hazards for the kiwifruit industry. Results from this project will guide future research investment. This project focussed on kiwifruit and similar fruits and ranked relevant food safety hazards and identified data gaps that impact the ranking (NZFSSRC, 2021c).

3.2.3 Case Study: The 2021 COVID-19 incident on NZ kiwifruit exports to China

In September 2021, a small sample of Zespri kiwifruit tested positive for COVID-19 at a wholesale market in China, prompting a rapid response from the marketer. The positive detection was a result of routine fruit testing at the wholesale market; further tests on related fruit came back negative. After that incident, Chinese authorities took steps ranging from temporarily removing fruit from shelves in areas where the fruit was distributed through to testing customers who purchased fruit where the affected batch was sold. Zespri confirmed that the fruit came from the Bay of Plenty and was packed in May 2021 before it was shipped from Tauranga in August 2021.

At that time, there were no reported cases of the virus in New Zealand's orchards or packhouses. Despite the World Health Organisation stating it was highly unlikely that people could contract COVID-19 from food or food packaging during the pandemic, China implemented strict COVID-19 food safety guidelines. This included testing imported products. While Zespri experienced some short-term market impact, the absence of trade disruptions was predominantly due to publication of NZFSSRC research findings showing there is no evidence that COVID-19 can be transmitted through food or food packaging (this is explained in more detail in the next section 3.2.4). All shipments into China were processed in accordance with standard protocols, including testing for COVID-19 and disinfecting to provide additional certainty (Kingsbury, 2022; Zespri, 24 Sep 2021; Food Safety News, 2022).

3.2.4 Role and value of NZFSSRC research into the possible transmission of COVID-19 via food and/or its packaging

The Centre played a significant role after the detection of positive COVID-19 cases in New Zealand kiwifruit exported to China in 2021. At the start of the pandemic, there was an emerging international and national concern about whether food consumption and food packaging might lead to COVID-19 infection. In response, the Centre undertook a comprehensive literature review of "*The possibility of transmission of COVID-19 via food or beverages and their packaging*" including industry-focussed reviews on COVID-19 risk. The review concluded that *'… **there is no evidence of food or food packaging being associated with transmission of COVID-19*** '(Kingsbury, 2022). The Centre made this review publicly available and undertook several revisions as further studies and insights were published. The review is currently in its seventh revision (April 2022).

This NZFSSRC-led research was significant to the food industry, nationally and internationally. The research avoided significant impacts and costs for the food sector and the economy as a whole. Personal communication with industry noted that other benefits were its timeliness, the regular updating of the research, and that all information was collated and published by one independent and scientifically credible institution – the NZFSSRC.

3.2.5 Economic value of the NZFSSRC research into the possible transmission of COVID-19 via food and/or its packaging

This section aims to calculate the economic value to the kiwifruit industry from the above described NZFSSRC-led research on "*The possibility of transmission of COVID-19 via food or beverages including their packaging*" after the COVID-19 incident in New Zealand kiwifruit in China in September 2021. As stated in personal communication with industry, the conclusion from the literature review that there was no evidence that COVID-19 can be transmitted through food intake or food packaging created two significant benefits to the kiwifruit industry:

(1) NZFSSRC avoided an approximate 3 to 6 month export ban of kiwifruit into China; and

(2) NZFSSRC avoided the unnecessary development of a global (ISO) Standard for food packaging, with ongoing requirements to test.

Maintaining market access for New Zealand kiwifruit into China

As mentioned above, industry interviews highlighted that without the timely provision of the results from the literature review on COVID-19 transmission from food and/ or its packaging, kiwifruit exports to China could have been halted for approximately 3 to 6 months. Table 3-5 shows New Zealand kiwifruit exports to China for the years 2021 and 2022. From the table it can be seen that in a calendar year, kiwifruit export season to China is from March to November, with peak export volumes sent between April and August.

Table 3-5: Kiwifruit exports to China in 2021 and 2022 (NZ$ million).

Month	2021	2022
	NZ$ million	
January	0	0
February	0	0
March	52.1	30.6
April	105.5	136.8
May	108.0	117.3
June	88.9	138.0
July	70.4	73.7
August	93.1	45.5
September	58.0*	36.6
October	61.9	41.0
November	17.6	26.0
December	0	0
Total	**655.6**	**645.4**

Note: *Event: Positive COVID-19 test results on NZ kiwifruit exports in China.
Source: StatsNZ (2023b).

In order to calculate the economic costs from stopped kiwifruit exports to China, we developed five time-based scenarios of kiwifruit export bans (see Table 3-6). We assumed that without the Centre's research, kiwifruit exports would have stopped immediately after the incident (which was in September 2021), beginning from October 2021. Results showed that, without the NZFSSRC-led research, economic costs for a 3 to 6 month export ban would have ranged from NZ$79.5 million (Scenarios 1, 2 and 3) to NZ$110 million (Scenario 4). Scenario 5 presents the worst-case scenario of an export halt during peak export season. The loss in export value in this scenario would have exceeded NZ$390 million in 2022.

It needs to be noted that these estimates are conservative, since it was possible that China could have stopped all New Zealand food exports for a longer period.

Table 3-6: Calculations of economic costs to New Zealand from a COVID-19 related kiwifruit export ban to China.

Scenario	Description	NZ$ million
1	3 month export ban to China after Sept 2021 incident (Oct-Dec 2021)	79.5
2	4 month export ban to China after Sept 2021 incident (Oct 2021 - Jan 2022)	79.5
3	5 month export ban to China after Sept 2021 incident (Oct 2021 - Feb 2022)	79.5
4	6 month export ban to China after Sept 2021 incident (Oct 2021 - Mar 2022)	110.2
5	3 month export ban during peak kiwifruit export season, (Apr - Jun 2022)	392.1

Note: Estimates are presented in 2021 prices.

Another impact related to the COVID-19 incident was mentioned in interviews with industry. This incident could have damaged brand reputation. As outlined in Guenther et al. (2022), food safety outbreaks can have a prolonged effect on the market due to reputation and brand damage of the company from a food safety incident. These indirect costs are often higher than the direct costs of the food safety incident, and typically last longer. These reputational and brand effects are almost impossible to measure. Nevertheless, companies may face substantial profitability losses if the food safety incident causes reputation damage that reduces the long-term demand for their products (Pozo & Schroeder, 2016).

Prevention of the development of an unnecessary global (ISO) standard for food packaging

Based on its concerns about the possible transmission of COVID-19 via imported food products and their packaging, China considered requiring all food imports to follow food packaging standards similar to ISO Standards. In response, the NZFSSRC delivered an opinion piece to an International Organisation for Standardisation (ISO) submission on the development of standardised methods to detect SARS-CoV-2 (the disease-causing agent for COVID-19) on surfaces. The opinion piece outlined up-to-date scientific evidence that an ISO testing method for SARS-CoV-2 on surfaces was not necessary because the virus cannot be transmitted through food or its packaging (Kingsbury, 2022; NZFSSRC, 2022b). If this standard had been implemented, it would have generated significant costs for New Zealand food producers, processors and exporters (and for the rest of the world).

To estimate the value of these avoided costs for the New Zealand economy, we constructed a scenario assuming that Chinese authorities implemented trade restrictions requiring all New Zealand food exporting companies to implement a food packaging standard. There is no ISO standard that refers to food packaging only, but the AERU researchers found three ISO standards that can include (food) packaging standards. These are ISO9001 (Quality Management Standard), ISO14001 (Environmental Management Standard), and ISO22000 (Food Safety Management Standard). In our judgement, the potential standard might have been similar to ISO22000, which focusses on the food industry and includes standards with specific food safety requirements for organisations in the food chain (ISO, 2022). In addition, the Food Safety System Certification (FSSC22000) for food safety/quality management is an internationally recognised scheme for food safety certification applicable to all organisations in the food chain.

In personal communications with AsureQuality (the FSSC/ ISO22000 auditor in New Zealand), we learned that ISO22000, as a stand-alone standard, is no longer recognised internationally. Most New Zealand food exporting companies are currently certified with FSSC/ ISO22000.

AsureQuality further highlighted that the costs for FSSC22000 certification will depend on many factors; for example, whether a certified management system has already been implemented, the size of the company and the complexity of the system. This will influence the duration of the audits and thus their costs. AsureQuality suggested that audit (only) costs for a small company would be approximately NZ$11,000; for a large company, audit costs could reach up to NZ$30,000. However, additional costs might be incurred during the audit process. In addition, there will be costs incurring pre-audit for changing processes in order to get the company 'audit ready'; these costs may include a consultant, costs for gap analysis and new equipment. Hence, costs can differ significantly per company.

For this analysis, we concentrated on the FSSC22000 Food Safety management standard audit costs. We assumed an audit cost of NZ$11,000 for New Zealand exporting enterprises with the size of 0-99 employees and NZ$30,000 for enterprises with 100+ employees. The number of New Zealand exporting companies by size and industry for 2021 is shown in Table 3-7.

Table 3-8 presents our analysis. If all New Zealand food exporting companies implemented the food packaging standard, the annual cost is approximately NZ$9.2 million for the audits. This is a conservative estimate since it does not include pre-audit costs mentioned above.

Table 3-7: Number of food exporting companies by size and selected ANZSIC[(1)] Codes, 2021.

Year 2021	Exporting		Exporting Total
A code	0-99 employees	100+ employees	
A011 Nursery and Floriculture Production	21	0	21
A012 Mushroom and Vegetable Growing	9	3	12
A013 Fruit and Tree Nut Growing	111	0	111
A014 Sheep, Beef Cattle and Grain Farming	33	0	33
A015 Other Crop Growing	15		15
A016 Dairy Cattle Farming	0		0
A017 Poultry Farming	0	3	3
A018 Deer Farming	0		0
A019 Other Livestock Farming	75	0	75
Total A	**264**	**6**	**270**
C111 Meat and Meat Product Manufacturing	21	27	48
C112 Seafood Processing	24	9	33
C113 Dairy Product Manufacturing	33	15	48
C114 Fruit and Vegetable Processing	36	6	42
C115 Oil and Fat Manufacturing	12	0	12
C116 Grain Mill and Cereal Product Manufacturing	6	6	12
C117 Bakery Product Manufacturing	18	12	30
C118 Sugar and Confectionery Manufacturing	12	3	15
C119 Other Food Product Manufacturing	147	12	159
Total C	**309**	**90**	**399**
Grand Total	**573**	**96**	**669**

Note: (1) ANZSIC codes is the Australian and New Zealand Standard Industrial Classification (ANZSIC).
Source: StatsNZ, 2023c.

Table 3-8: Calculations of economic costs from an assumed food packaging standard implementation for New Zealand food exporting firms.

	No. of export firms; 0-99 employee size	No. of export firms; 100+ employee size	FSSC 22000 Food Safety management standards audit cost; 0-99 employee size, NZ$	FSSC 22000 Food Safety management standards audit cost; 100+ employee size, NZ$	Total Economic cost for FSSC 22000 Food Safety management standards audit, NZ$
Exporting primary producers	264	6	11,000	30,000	3,084,000
Exporting food processing companies	309	90	11,000	30,000	6,099,000
Total	**573**	**96**			**9,183,000**

3.2.6 Summary

This section has estimated the Centre's contributions to the New Zealand economy because of their involvement with the New Zealand kiwifruit industry in assessing and preventing food safety related incidents. A case study was developed to monetise the impact of the Centre's timely provision of insights through their literature review on "*The possibility of transmission of COVID-19 via food or beverages including their packaging*" that concluded that *'… **there is no evidence of food or food packaging being associated with transmission of COVID-19*** '(Kingsbury, 2022). This NZFSSRC-led research led to two significant benefits that were used to estimate an economic value from this research.

(1) NZFSSRC research avoided an approximately 3 to 6 month export ban of kiwifruit into China. The calculations resulted in a range of prevented economic costs of NZ$79.5 million (3 month export ban) to NZ$110.2 million (6 month export ban).

(2) NZFSSRC research avoided the development of an unnecessary global (ISO) Standard for COVID-19 food packaging. The calculations resulted in a benefit of NZ$9.2 million annually from avoiding audit costs for food packaging for all New Zealand food exporting companies.

3.3 NZFSSRC contributions to the poultry industry in New Zealand

This section describes the Centre's contributions to the New Zealand economy from its involvement with the New Zealand poultry industry in assessing and preventing food safety related incidents. The Centre has enabled advances to be made in tackling some of the most longstanding and challenging food safety issues in New Zealand such as Campylobacter contamination in poultry. This section uses a case study aimed at calculating the economic value to the industry from the NZFSSRC-led longitudinal study on tracking Campylobacter in poultry flocks.

3.3.1 New Zealand's poultry industry

New Zealand's poultry industry is comprised of chicken, duck and turkey production, as well as table egg production. The Poultry Industry Association of New Zealand (PIANZ) represents the interests of the primary poultry meat producers and processors in New Zealand. It ensures that producers and processors meet standards in animal welfare, stockmanship and food safety (PIANZ, 2022).

In 2021, there were 270 poultry meat farming businesses in New Zealand, producing a total of 121 million birds which made 224,398 tonnes of poultry meat (Figure NZ, 2022; PIANZ, 2022). The four largest poultry processors in New Zealand are Tegel, Inghams, Brinks and Turks. New Zealand poultry production is predominantly for domestic consumption, with only small amounts being exported. In 2022, New Zealand poultry meat exports were valued NZ$43 million (StatsNZ, 2023b).

3.3.2 Food safety issues in the New Zealand poultry industry

The main pathogens in poultry meat and eggs that can be harmful to humans are Campylobacter, Salmonella and Listeria.

Campylobacteriosis is one of the largest bacterial foodborne diseases in New Zealand. Campylobacteriosis is a type of gastroenteritis caused by the bacteria Campylobacter. Symptoms usually develop 2 to 5 days after becoming infected with the bacteria. The illness can be of variable severity with symptoms of abdominal pain, fever, diarrhoea, nausea and vomiting. It rarely develops into chronic (long-term) illnesses like reactive arthritis and Guillain-Barré Syndrome (Ministry of Health, 2021).

Since campylobacteriosis became notifiable in New Zealand in 1980, the number of cases recorded rose steadily. By the mid-2000s New Zealand was recognised as having the largest campylobacteriosis case rate of any high-income country, peaking at 15,873 notifications or 383.5 per 100,000 in 2006. Gadiel (2010) estimated that treatment costs for campylobacteriosis were NZ$2 million in New Zealand in 2009. This amounted to NZ$36 million after adding output loss (NZ$18 million) and residual private costs (NZ$16 million). Gadiel (2010) concluded that campylobacteriosis is the costliest recognisable foodborne disease in New Zealand.

Campylobacter is commonly found in animals and the environment. It can manifest as a foodborne infection from eating undercooked meats, with poultry meat recognised as the major cause of New Zealand's infections, representing 84 per cent of all foodborne Campylobacter infections (followed by 14 per cent from cattle and 2 per cent that is unknown). Other sources of foodborne campylobacteriosis may include red meat and unpasteurised milk. However, these are much less important than poultry in contributing to New Zealand's cases of campylobacteriosis (Gadiel, 2010; Hancock, 24 Sep 2022).

In 2006, in response to the large numbers of campylobacteriosis in New Zealand, the New Zealand Food Safety Authority (NZFSA), a predecessor organisation to New Zealand Food Safety (NZFS), in association with the poultry industry implemented a Campylobacter strategy in the Poultry Risk Management Strategy. The sampling and testing programme for poultry broilers began under the National Microbiological Database (NMD). The Strategy includes measures such as performance targets to reduce Campylobacter counts on broiler carcasses after primary processing and public education about hygienic handling of poultry. By April 2008 a Campylobacter performance target had been developed by the regulator (NZFSA, 2008).

Between 2006 and 2008, the poultry industry, through science and research, developed interventions and activities to reduce pathogen loading on the bird on farm and through primary processing. The benefit from these research and industry actions to comply with the new standards resulted in an immediate 58 per cent reduction in notifiable cases of campylobacteriosis in New Zealand. Duncan (2014) estimated that from an annual cost of NZ$99 million for Campylobacter illness at the beginning of 2007, the reduction in notifications led to a reduced cost of NZ$41.6 million over 2007/2008; a benefit of NZ$57.4 million (Duncan, 2014).

The Campylobacter performance targets are reviewed and revised regularly. In July 2021, new limits were introduced for the number of chicken carcasses allowed with Campylobacter. The new rules limit how many infected samples can be in a three-week moving window during processing. Out of 45 samples, two are allowed levels above 6000 colony forming units (cfu) and 10 above 200 cfu (Hancock, 24 Sept 2022).

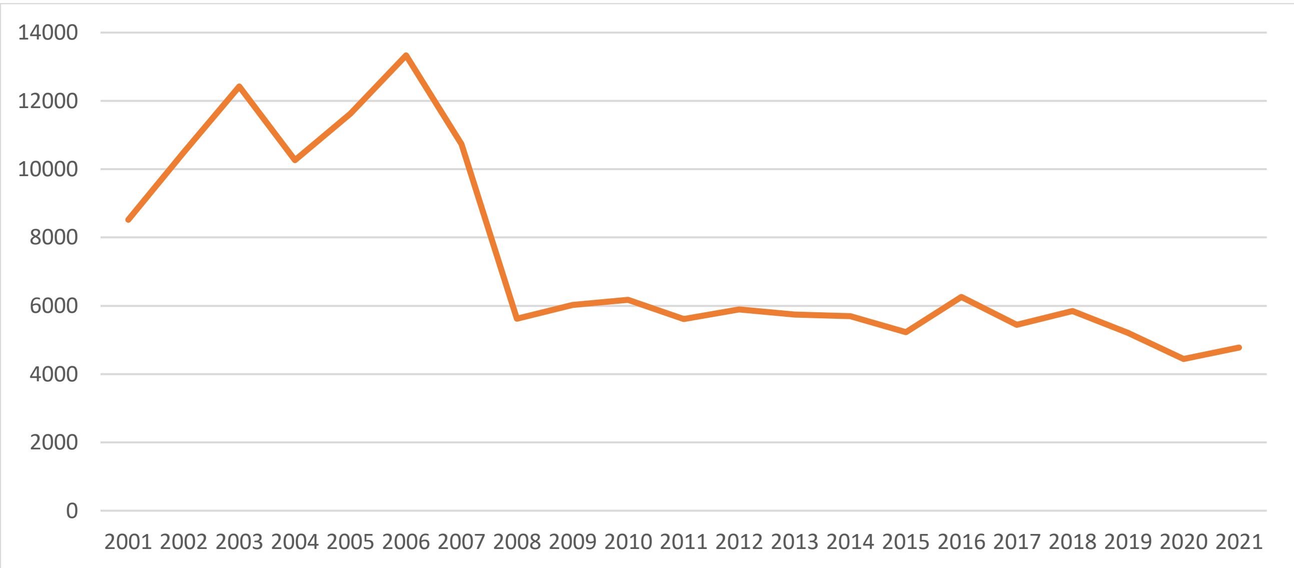
Although improvements have been made and maintained by the poultry industry in both the presence and levels of Campylobacter in chickens (see Table 3-9), the reduction to the rate of human cases has plateaued in recent years with around 4,500 cases annually (see Figure 3-1 and Table 3-10) (NZFS, 2019; NZFS, 2017b). NZFS aims for a further 20 per cent reduction in foodborne cases of Campylobacter by the end of 2024, aiming to drop cases to 70 per 100,000 people by 2024, currently sitting at 88 per 100,000 people (Hancock, 24 Sept 2022).

Table 3-9: Positive samples of Campylobacter at processing stage, 2007 – 2018.

Year	Percentage of positive samples of Campylobacter on poultry at standard through put operators	Number of positive samples of Campylobacter on poultry at standard through put operators
	%	n
2007	52	1,416
2008	38	2,273
2009	33	1,990
2010	39	2,252
2011	38	2,346
2021	33	2,068
2013	35	2,108
2014	29	1,831
2015	26	1,698
2016	24	1,598
2017	17	1,137
2018	17	1,121

Note: Results from a standard throughput premises only.
Source: NZFS, 2019; Hancock, 24 Sept 2022.

Figure 3-1: Campylobacteriosis cases from poultry in New Zealand, 2001 – 2021.



Source: ESR 2022; Hancock, 24 Sept 2022; NZFS, 2019.

Table 3-10: Campylobacter cases per 100,000 people, 2005 – 2024 (MPI target).

Year	Campylobacter cases per 100,000 people	Campylobacter cases per 100,000 people, foodborne
2005	370.2	236.2
2006	424.4	271
2007	302.2	192.8
2008	156.8	100
2009	166.3	106.1
2010	170.2	108.6
2011	153.3	97.8
2012	159.7	101.9
2013	154.2	98.4
2014	151.4	96.6
2015	138.1	88.1
2016	162.2	103.5
2017	138.2	88.1
2018	142.4	n/a
2019	124.6	n/a
2020	104.1	n/a
2021	111.8	n/a
2022	n/a	n/a
2023	n/a	n/a
2024*	n/a	70*

Note: * NZFS aims for a further 20 per cent reduction in foodborne Campylobacter cases by the end of 2024.
Source: NZFS, 2019; NZFS, 2022; ESR, 2023.

Salmonella is another important pathogen causing large numbers of foodborne disease in New Zealand. The trend in overall salmonellosis notifications has increased since the mid-1990s, peaking in 2001 (Lim et al., 2010). Since then, case numbers have decreased slowly. In 2021, there were 13.9 cases per 100,000 people (ESR, 2023). Although no single primary exposure pathway has yet been established in New Zealand, the emphasis in incorporating salmonellosis in NZFS's five-year organisational target provided a better understanding of its sources. Explanations for the spread of salmonellosis are diverse and include outbreaks associated with poultry, raw carrots, flour, watermelon and retail food outlets. (Lim et al., 2010; Gadiel, 2010; NZFS, 2019).

An outbreak of *Salmonella* Enteritidis was detected in New Zealand's commercial chicken producer and primary processor flocks in 2021. Although S. Enteritidis is not new to New Zealand, it is new to domestic commercial chicken flocks which presents risks to human and animal health as well as to international trade. During the outbreak, S. Enteritidis was also found in environmental samples from a North Island chicken hatchery that supplies a number of chicken meat and egg producers. There were forty-six human cases from this incident and more than 550,000 birds had to be killed. Following extensive investigation, a new regulatory framework for the industry was designed and implemented (Treasury, 2022b; RNZ, 2022; Food Safety News, 2021; Food New Zealand, 2022).

Another key pathogen causing foodborne illness in humans from poultry is *L. monocytogenes.* A detailed description of Listeria was provided in Section 3.2.1

Overall, food safety outbreaks from these pathogens are costly to the New Zealand economy. In a comprehensive assessment of the economic impact of six foodborne diseases in New Zealand, Gadiel (2010) showed that campylobacteriosis costs the economy NZ$36 million or 27 per cent of total disease-specific costs annually. This is followed by salmonellosis (NZ$16 million, 12 per cent) and listeriosis (NZ$15 million, 11 per cent) (see Table 3-11). To date, Gadiel's (2010) study is the most detailed and extensive study in New Zealand for estimating the annual costs of foodborne diseases by pathogens to the New Zealand economy.

Table 3-11: Total cost estimates for foodborne disease in New Zealand, 2009, NZ$ million.

Illness	Treatment costs	Output loss	Residual private costs	Total
Campylobacteriosis	2.2	17.8	16.0	36.0
Salmonellosis	0.2	0.4	14.9	15.5
Listeriosis	0.7	0.1	14.4	15.2

Source: Gadiel, 2010.

3.3.3 Role and value of the NZFSSRC in the poultry industry

The Centre plays an important role for the poultry industry in New Zealand; predominantly through supporting and funding research projects, aimed at reducing the risks of food safety outbreaks from poultry meat. Some NZFSSRC projects with the poultry industry are described below.

In interviews with industry one project in particular was highlighted as having a significant impact to the industry. In 2020, the Centre, in collaboration with industry, conducted a longitudinal study tracking Campylobacter in poultry flocks. The aim of this study was to validate and assess the efficacy of current broiler poultry processing steps and interventions, and therefore identify future foci and research priorities to reduce Campylobacter in broilers. It also aimed to provide a better understanding of on-farm sources for Campylobacter contamination of broiler flocks in a longitudinal broiler farm micro-biological survey (NFSSRC, 2020). Industry interviews emphasised that this longitudinal study is valuable to the industry as research findings enable companies and plants to improve the process when a positive case of Campylobacter is detected.

Another important project funded by the Centre in 2019, in collaboration with industry, was aimed at controlling Campylobacter in chickens. The project enabled the poultry industry to develop on-farm risk management practices that prevent contamination of broiler flocks with Campylobacter. In this project, potential pre-processing sources of Campylobacter in broilers were investigated by sampling multiple environmental and shed-based potential sources. Campylobacter isolates were then correlated with strains in the flock by comparing WGS of isolates. This led to the development of farm practices that reduced risk for domestic poultry consumers and improved safety for farm and processing workers (NFSSRC, 2019b).

3.3.4 Case Study: Economic value from NZFSSRC longitudinal study on tracking Campylobacter in poultry flocks

Interview participants highlighted the significant value of the NZFSSRC-led longitudinal study on tracking Campylobacter throughout the poultry processing line. This section aims to calculate the economic value from this research. Personal communications with the industry explained that the Centre's research findings enable processing companies to track pathogens faster. Hence, companies are avoiding costs arising from a slowed-down production process or a temporary plant closure from positive Campylobacter cases. Interview participants pointed out it is difficult to assign a dollar value to this benefit. In our calculations, we focus on the saved costs from the prevention of 'slowing down processing' or from the worst-case scenario of 'temporary plant closure' from Campylobacter detection in the plant. Data used in these calculations were predominantly provided by interview participants unless stated otherwise.

The daily testing process for Campylobacter in a standard processing plant was described by industry participants as follows. Three birds per day per processing plant are tested for Campylobacter. In the case of a positive test result, response procedures come into force that include more testing, cleaning, sanitisation, etc. In the worst case, the processing plant closes for further investigation and sanitisation. With each increase in response level to Campylobacter detection, production speed is slowed down with fewer birds being processed per hour due to extra testing, cleaning, etc. For example, instead of 60,000 birds processed in an 8-hour-day, production is extended to 10 to 12 hours. This incurs extra costs to the processor for wages, electricity, gas, sanitisation, etc. This also creates flow-on issues such as delayed deliveries to secondary processing plants, which also increases costs for the processor.

Table 3-12 presents the running costs for a standard poultry processing plant provided by an interview participant. The estimates of daily operating costs range between NZ$30,000 and NZ$80,000 depending on plant size, driven by wages, sanitisation inputs and general costs. For our calculations, we used the average of this range, estimating operations costs of NZ$55,000 per day.

Table 3-12: Poultry processing plant operational costs.

Operational costs of poultry processing plant per day in NZ$	Production hours per day	Birds processed per day
55,000	8	60,000
6,875	1	7,500

Source: Pers. Comm., 1 Feb 2023; 24 April 2023.

Our calculations focus on the costs from extended production time for extra testing, cleaning, electricity, gas, wages, etc., caused by detection of a positive Campylobacter case during processing. In 2018, there were 1,121 cases of Campylobacter on poultry in processing plants (see Table 3-9). We assume that all of these cases occur separately. This might be an overstatement. However, we could not find data on how many of these cases were linked or found in one test run. As mentioned in industry interviews, production time could be extended between 2 to 4 hours from a detection of a positive case in a processing plant.

Table 3-13 shows the range of additional costs occurring from positive cases in the processing stage. If all 1,121 positive cases led to a two-hour extended processing time, costs would be NZ$15.4 million. This would increase to NZ$30.8 million for an extension of production by 4 hours for all 1,121 cases. These costs do not include the costs for flow-on issues, for example for the delayed delivery to the secondary processor. In addition, as mentioned in interviews, the worst case is a temporary plant closure; however, we do not know how often this happens. The cost of temporary plant closure would range between NZ$30,000 and NZ$80,000 per day depending on the size of the processing plant as reported by the interview participant.

Table 3-13: Calculations: costs prevented from NZFSSRC longitudinal study on tracking Campylobacter in poultry flocks, in NZ$.

	Minimum, NZ$ (Production extended by 2 hours)	**Maximum, NZ$ (Production extended by 4 hours)**
1,121 cases of Campylobacter at processing stage (2018) (NZFS, 2019).	15,413,750	30,827,500

3.3.5 NZFSSRC supports NZFS's 20 per cent reduction target in Campylobacter infections

As stated earlier, NZFS has set a 20 per cent reduction target of Campylobacter infections by 2024. NZFSSRC will support the government to achieve this target by bringing together NZFS, researchers and the poultry industry to ensure they are working collaboratively to agree and prioritise research funding.

Table 3-14 shows poultry industry data and the number of Campylobacter cases from poultry from 2014 to 2021. Campylobacter cases have plateaued in the past few years. To obtain the total costs for poultry related foodborne Campylobacter cases, we used the cost-per-case estimate of NZ$1,054.97 provided by Gadiel (2010) and adjusted to 2021 prices. Based on 2021 case numbers of 4,776, a 20 per cent reduction would be a further drop of 955 cases, totalling to 3,821 cases per annum. As a result, this would save the New Zealand economy NZ$1,007,496 annually.

Table 3-14: Poultry industry data and Campylobacter cases and their costs to NZ economy, 2014 – 2021.

	Production		Consumption	Campylobacter Cases from poultry	Total Costs NZ$*
Year	**Birds '000s**	**Tonnes**	**Tonnes**	**n**	**NZ$**
2014	101,142	189,667	128,000	5,696.88	6,010,037.49
2015	110,589	204,342	126,000	5,223.12	5,510,234.91
2016	115,094	219,482	124,000	6,263.04	6,607,319.31
2017	118,370	231,016	123,000	5444.88	5,744,185.05
2018	125,496	249,711	121,000	5,843.88	6,165,118.08
2019	120,745	235,939	136,000	5,210.52	5,496,942.28
2020	118,702	224,111	125,000	4,441.92	4,686,092.34
2021	120,739	229,744	n/a	4,776.24	5,038,789.91

*Cost per case derived from Gadiel (2010); adjusted to 2021 prices = NZ$1,054 per case.
Sources: Production data, PIANZ, 2020; Consumption data, FAO, 2022; Campylobacter cases from poultry ESR 2022; Hancock, 24 Sept 2022.

3.3.6 Summary

This section examined the Centre's contributions to the New Zealand economy because of their involvement with the New Zealand poultry industry in assessing and preventing food safety related incidents. A case study was developed estimating the economic value from the NZFSSRC-led longitudinal study on tracking Campylobacter throughout the poultry processing line. As described in industry interviews, this research avoids the 'slowing down' of processing if a positive case of Campylobacter is detected at the processing stage.

Our calculations estimated that prevented costs from the Centre's research range between NZ$15 million and NZ$31 million per annum by avoiding an extension of processing by 2 to 4 hours for 1,121 cases annually. It was assumed that these are all individual cases, occurring separately, because data could not be found on how many of these cases are linked and found in one test run. These figures do not include any associated costs with flow-on issues from the delay.

Further, NZFSSRC is supporting NZFS's target to reduce Campylobacter cases by 20 per cent by 2024. The Centre is facilitating discussions and encouraging collaboration between NZFS and the poultry industry.

Chapter 4
Whole Genome Sequencing

Whole Genome Sequencing (WGS) is a key research capability of the NZFSSRC. This chapter describes the use of this technology in the food industry and outlines benefits and barriers.

4.1 The use of WGS in the food industry

Whole Genome Sequencing technology is increasingly used by food safety authorities and public health agencies – nationally and internationally – to facilitate the detection, investigation, and control of foodborne bacterial outbreaks, as well as food regulatory and other activities in support of food safety (Brown et al., 2019). WHO (2018) states that "*WGS provides the highest possible microbial subtyping resolution available to public health authorities for the surveillance of and response to foodborne diseases*." WGS represents an all-in-one approach to microbial identification and discrimination, replacing multiple traditional laboratory testing methods (Diplock, 2022). The technology provides better strain discrimination than other methods for typing foodborne bacterial pathogens (WHO, 2018). WGS can identify the unique fingerprint of foodborne pathogens found in food products and allows food safety experts to identify an organism's DNA sequence fast and efficiently. The technology provides an increased resolution, down to one DNA or RNA 'letter' (nucleotide) difference, between isolates. Hence, this technology can improve consumers' food safety and supports source traceability of food safety outbreaks fast (WHO, 2018; Food New Zealand, 2021).

Several studies have been published on the use of WGS for a specific foodborne disease or outbreak. In a systematic literature review Diplock (2022) provided recent examples of the use of WGS in foodborne disease outbreaks. These are listed in the Table 4-1.

Table 4-1: Examples of the use of WGS in foodborne disease outbreaks (Diplock, 2022).

Title	Year	Full Reference
Genetic diversity of Listeria monocytogenes strains contaminating food and food producing environment as single based sample in Italy (retrospective study)	2022	Acciari VA, Ruolo A, Torresi M, Ricci L, Pompei A, Marfoglia C, et al. Genetic diversity of Listeria monocytogenes strains contaminating food and food producing environment as single based sample in Italy (retrospective study). Int J Food Microbiol. 2022 Apr;366:109562.
Whole Genome Sequencing of Shigella sonnei through PulseNet Latin America and Caribbean: advancing global surveillance of foodborne illnesses	2017	Baker KS, Campos J, Pichel M, Della Gaspera A, Duarte-Martínez F, Campos-Chacón E, et al. WGS of Shigella sonnei through PulseNet Latin America and Caribbean: advancing global surveillance of foodborne illnesses. Clin Microbiol Infect. 2017 Nov;23(11):845-53
Highly Pathogenic Clone of Shiga Toxin-Producing Escherichia coli O157:H7, England and Wales	2018	Eykelbosh A, Fong D. Conducting a literature search & semi-systematic review: the NCCEH approach. Vancouver, BC: National Collaborating Centre for Environmental Health; 2017
Characterization of Emetic and Diarrheal Bacillus cereus Strains From a 2016 Foodborne Outbreak Using Whole-Genome Sequencing: Addressing the Microbiological, Epidemiological, and Bioinformatic Challenges	2019	Carroll LM, Wiedmann M, Mukherjee M, Nicholas DC, Mingle LA, Dumas NB, et al. Characterization of emetic and diarrheal bacillus cereus strains from a 2016 foodborne outbreak using whole-genome sequencing: addressing the microbiological, epidemiological, and bioinformatic challenges. Front Microbiol. 2019 Feb;10.
Whole-Genome Sequencing of Salmonella Mississippi and Typhimurium Definitive Type 160, Australia and New Zealand	2019	Ford L, Ingle D, Glass K, Veitch M, Williamson DA, Harlock M, et al. Whole-genome sequencing of salmonella Mississippi and typhimurium definitive type 160, Australia and New Zealand. Emerg Infect Dis. 2019 Sep;25(9):1690-7.
Investigation of Outbreaks of Salmonella enterica Serovar Typhimurium and Its Monophasic Variants Using Whole-Genome Sequencing, Denmark	2017	Gymoese P, Sørensen G, Litrup E, Elmerdal Olsen J, Møller Nielsen E, Torpdahl M, et al. Investigation of outbreaks of salmonella enterica serovar typhimurium and its monophasic variants using whole-genome sequencing, Denmark. Emerg Infect Dis. 2017 Oct;23(10):1631-9
Large Nationwide Outbreak of Invasive Listeriosis Associated with Blood Sausage, Germany, 2018–2019	2020	Halbedel S, Wilking H, Holzer A, Kleta S, Fischer MA, Lüth S, et al. Large nationwide outbreak of invasive listeriosis associated with blood sausage, Germany, 2018-2019. Emerg Infect Dis. 2020 Jul;26(7):1456-64.
Ability of Whole-Genome Sequencing to Refine a Salmonella I 4,[5],12:i:- Cluster in New York State and Detect a Multistate Outbreak Linked to Raw Poultry	2021	Huth P, Wirth SE, Baker D, Nicholas DC, Douris A, Freiman J, et al. Ability of whole-genome sequencing to refine a salmonella I 4,[5],12:i:-cluster in New York state and detect a multistate outbreak linked to raw poultry. Food Prot Trends. 2021 Mar;41(2):239-45
Whole-Genome Sequencing to Detect Numerous Campylobacter jejuni Outbreaks and Match Patient Isolates to Sources, Denmark, 2015–2017	2020	Joensen KG, Kiil K, Gantzhorn MR, Nauerby B, Engberg J, Holt HM, et al. Whole-genome sequencing to detect numerous campylobacter jejuni outbreaks and match patient isolates to sources, Denmark, 2015-2017. Emerg Infect Dis. 2020 Mar;26(3):523-32. https://doi.org/10.3201/eid2603.190947
Nationwide outbreak of invasive listeriosis associated with consumption of meat products in health care facilities, Germany, 2014–2019	2021	Lachmann R, Halbedel S, Adler M, Becker N, Allerberger F, Holzer A, et al. Nationwide outbreak of invasive listeriosis associated with consumption of meat products in health care facilities, Germany, 2014–2019. Clin Microbiol Infect. 2021 Jul;27(7):1035. https://doi.org/10.1016/j.cmi.2020.09.020.
Whole-Genome Analysis of Salmonella enterica Serovar Enteritidis Isolates in Outbreak Linked to Online Food Delivery, Shenzhen, China, 2018	2020	Min J, Feng Z, Chao Y, Yinhua D, Kwan PSL, Yinghui L, et al. Whole-genome analysis of salmonella enterica serovar enteritidis isolates in outbreak linked to online food delivery, Shenzhen, China, 2018. Emerg Infect Dis. 2020 Apr;26(4):789-92. https://doi.org/10.3201/eid2604.191446.

Title	Year	Full Reference
Real-Time Whole-Genome Sequencing for Surveillance of Listeria monocytogenes, France	2017	Moura A, Tourdjman M, Leclercq A, Hamelin E, Laurent E, Fredriksen N, et al. Real-time wholegenome sequencing for surveillance of listeria monocytogenes, France. Emerg Infect Dis. 2017 Sep;23(9):1462-70
Application of Whole-Genome Sequences and Machine Learning in Source Attribution of Salmonella Typhimurium	2020	Munck N, Njage PMK, Leekitcharoenphon P, Litrup E, Hald T. Application of whole-genome sequences and machine learning in source attribution of salmonella typhimurium. Risk Anal. 2020;40(9):1693-705
Use of whole-genome sequencing for public health intervention: outbreak investigation of a cluster of cases of salmonella foodborne illness in England, 2016	2018	Olufon O, Seale AC, Iyanger N, Wynne-Evans E. Use of whole-genome sequencing for public health intervention: outbreak investigation of a cluster of cases of salmonella foodborne illness in England, 2016. The Lancet. 2018 Nov;392(Supplement 2):S10-S.
Genetic characterization of norovirus GII.4 variants circulating in Canada using a metagenomic technique	2018	Petronella N, Ronholm J, Suresh M, Harlow J, Mykytczuk O, Corneau N, et al. Genetic characterization of norovirus GII.4 variants circulating in Canada using a metagenomic technique. BMC Infect Dis. 2018 Oct;18(1):1-11.
Application of whole-genome sequencing for norovirus outbreak tracking and surveillance efforts in Orange County, CA	2021	Silva AJ, Yang Z, Wolfe J, Hirneisen KA, Ruelle SB, Torres A, et al. Application of whole-genome sequencing for norovirus outbreak tracking and surveillance efforts in Orange County, CA. Food Microbiol. 2021 Sep;98:103796.
Escherichia coli O103 outbreak associated with minced celery among hospitalized individuals in Victoria, British Columbia, 2021	2022	Smith C, Griffiths A, Allison S, Hoyano D, Hoang L. Escherichia coli O103 outbreak associated with minced celery among hospitalized individuals in Victoria, British Columbia, 2021. Can Commun Dis Rep. 2022 Jan;48(1):46-50
Genome-wide networks reveal emergence of epidemic strains of Salmonella Enteritidis	2022	Svahn AJ, Chang SL, Rockett RJ, Cliff OM, Wang Q, Arnott A, et al. Genome-wide networks reveal emergence of epidemic strains of Salmonella Enteritidis. Int J Infect Dis. 2022 Apr;117:65-73
Outbreak of Reading in persons of Eastern Mediterranean origin in Canada, 2014–2015	2017	Tanguay F, Vrbova L, Anderson M, Whitfield Y, Macdonald L, Tschetter L, et al. Outbreak of reading in persons of Eastern Mediterranean origin in Canada, 2014-2015. Can Commun Dis Rep. 2017 Jan;43(1):14-20
Linking Epidemiology and Whole-Genome Sequencing to Investigate Salmonella Outbreak, Massachusetts, USA, 2018	2020	Vaughn EL, Vo QT, Vostok J, Stiles T, Lang A, Brown CM, et al. Linking epidemiology and wholegenome sequencing to investigate salmonella outbreak, Massachusetts, USA, 2018. Emerg Infect Dis. 2020 Jul;26(7):1538-41.
Phylogenetic structure of Salmonella Enteritidis provides context for a foodborne outbreak in Peru	2020	Willi Q, Junior C-C, Orson M, Carmen VH, Maria LZ, Ronnie GG. Phylogenetic structure of Salmonella Enteritidis provides context for a foodborne outbreak in Peru. Sci Rep. 2020 Dec;10(1):1-6

Source: Diplock, 2022.

A number of global WGS platforms have been developed to support the identification and investigation of foodborne outbreaks. These platforms are accumulating global sequence data and aim to share them in real time. The databases use metadata including WGS metagenomics, data from industry biosensors, and consumer data (Diplock, 2022). Some of the important platforms are:

- Integrated Rapid Infectious Disease Analysis (IRIDA), Canada;
- GenomeTrakr, USA;
- PulseNet, USA and international;
- HealthMap Foodborne Dashboard, USA;
- Global Microbial Identifier (GMI), Denmark.

These data-sharing platforms have proven successful in saving economic and health costs from foodborne disease outbreaks. In their economic evaluation of the GenomeTrakr WGS Network for *E. coli*, Listeria, and Salmonella, Brown et al. (2021) stated that illness numbers of heavily sequenced pathogens are falling faster relative to non-sequenced pathogens. They further noted that the net benefits from this are somewhere between US$100 million and US$450 million. These benefits of GenomeTrakr easily outweigh the costs of implementation after the second year. Once the program is fully implemented, net benefits might measure in billions of US dollars (Brown et al., 2021).

In addition, Scharff et al. (2016) undertook an economic evaluation of the network PulseNet in the US. The researchers estimated that the program prevents at least 270,000 foodborne illnesses and leads to savings of over US$500 million in medical and productivity costs annually (Scharff, 2016). Whole Genome Sequencing provides numerous improvements over traditional laboratory methods. According to Diplock (2022) these are as follows:

- Increased resolution and discrimination of pathogenic organisms;
- Earlier detection with less pathogenic material present;
- Enhanced clarity of linkages and source attribution for outbreak investigations;
- All-in-one testing method for clinical, food and environmental samples;
- Ability to assess evolutionary relatedness, antimicrobial resistance, and virulence;
- Open databases for sharing real-time data of pathogenic isolates globally, enhancing the identification and investigation of multijurisdictional outbreaks.

4.1.1 Examples of NZFSSRC WGS work

The establishment of the NZFSSRC has accelerated the development and use of WGS for food safety research and food safety risk management in New Zealand. Almost all food industries have been involved in a collaborative research project with the NZFSSRC involving WGS of pathogens. The NZFSSRC has facilitated the development of projects on WGS with early industry adopters of this technology, particularly with one dairy company. These projects have addressed specific questions around the identification, source attribution and control of pathogens. The demonstrated success of WGS in addressing food safety risk management has led to further industry interest such as commissioning WGS-based research projects in the poultry industry, other dairy companies and the salmon industry, among others. In all cases, the industry participants recognised the benefits of WGS helping them to trace and control pathogens in production.

In interviews with industry, one company stated that the work carried out by NZFSSRC in facilitating WGS services has been "*the foundation block*" of their Listeria management programme. In particular, the firm stated that, prior to the use of WGS, methods for pathogen detection and identification would be correct approximately 80 per cent of the time. The participant stressed that *" …the other 20 per cent meant that we would close down, we would spend between NZ$40,000-NZ$60,000, resurface all our floors, recoat our walls, come back online and the issue has gone away*." The participant further explained that this would happen approximately every two years.

Another interview participant stated that *"For techniques like WGS, it is very helpful to have the expertise in the NZFSSRC that can advise and keep us up-to-date with techniques, new methodologies…".*

In New Zealand, there is currently one shared WGS database which is used for food safety applications. This is the WGS database for *L. monocytogenes* for New Zealand isolates which includes over 1000 isolate sequences. The database was developed and established by ESR, a research collaborator to the NZFSSRC, funded through a NZFSSRC project. The isolates in the WGS database are from historical clinical cases and anonymous company environmental and food samples. This is designed to be a confidential reference repository for NZFSSRC members.

The database is not a public health surveillance tool. To protect contributing members' data no sensitive or identifiable information, such as company names or locations, food products or sectors, are included. Authorised access to the database is required. The database allows NZFSSRC members to compare WGS data for a selection of isolates of interest. The database has already been shown to be an invaluable resource for food safety in determining the relationships between current and previous Listeria cases (clinical and environmental) (NZFSSRC; 2021d).

In interviews with industry, participants identified specific cases of NZFSSRC assistance in facilitating and deploying WGS systems in production. One New Zealand dairy firm stated they worked with the NZFSSRC in deploying a WGS system as a tool within their Risk Management Programme. This work started with a case study, in which the firm worked with both NZFSSRC and MPI to map genomic sequences within their processing plants. The initial project led to the deployment of full in-house WGS processes that have been "*heavily preventative for food safety recalls*" and very helpful in managing risks. Specifically, the firm stated this has meant that they are able to keep their plants open for much longer, with no recall costs, and a safer public as a result.

An interview participant from the kiwifruit industry referred to a useful research project involving WGS on the "*identification of sources of contamination from kiwifruit orchards*". The interview participant stressed that the main benefit of this research project was to understand the spread of contamination. The participant stated:

> *This is a flagship NZFSSRC project, and the nuts and bolts of quite rigorous sampling. WGS was really helpful as it allowed us to make links between certain sub-species found in the orchard versus the pack-house. It's a huge piece of work – hundreds of samples, 17 pack-houses – all heavily subsidised by the NZFSSRC.*

In NZFSSRC interviews with industry partners, several food safety incidents were described where a pathogen was detected, allowing a timely removal and disposal of the product. The Centre found that these incidents cost the industry between NZ$0.5 million and NZ$2.4 million. The companies further noted that with WGS findings at hand, they have implemented a range of strategies to tackle these pathogens and minimise future impact. These strategies include changing sanitation protocols to help remove the pathogen from processing, replacing problematic infrastructure, and the identification of 'hot spots' to target for regular testing (Food New Zealand, 2021).

4.2 Benefits of WGS

Studies have examined the potential benefits of the use of WGS in a public health context. In the study mentioned above, Brown et al. (2021) evaluated the economic impacts of the FDA's GenomeTrackr WGS Network – a food safety database used by the US food industry. Their study examined the effects of GenomeTrackr to trace sources of three pilot pathogens – *E. coli*, Listeria and Salmonella. Using FDA response data on foodborne disease outbreaks between 1999 and 2019, Brown et al. (2021) estimated that, by 2019, the value of annual health benefits to the US economy was around US$500 million (including multipliers for underreporting and underdiagnosis), compared with an approximate investment of US$22 million by public agencies.

Multiple studies have indicated that WGS has the best discriminatory power (i.e. the ability to determine differences between strains) of any testing method for potential pathogens in a food safety context (Kjiln, 2022). Alleweldt et al. (2021) stated that case study participants ranked the accuracy of WGS as one of the key benefits of its use, since WGS produces results that are more detailed, accurate, specific, and sensitive. Additionally, WGS simplifies laboratory workflows, and reduces the time needed for analysis. This was supported by interview participants who reported that WGS allows them to precisely map potentially problematic pathogen strains that could disrupt production.

Brown et al. (2021) pointed out that a unique advantage of using WGS in food safety is that outbreaks may be identified at an earlier stage. In the case of Listeria, for example, since the application of WGS the average size of outbreaks has become smaller with more outbreaks being solved, and being solved faster (Jackson et al., 2016). With early intervention and the timely response of regulators and industry, outbreaks may be controlled before they spread (Brown et al., 2019). Diplock (2022) added that earlier elimination of sources decreases associated health and economic costs.

4.3 Barriers for industry uptake and limitations of WGS

A key limitation of WGS, as identified by NZFSSRC industry members, is its cost, particularly the initial investment required, with participants indicating that *"WGS is not cheap"*. However, almost all interviewed industry members stated that the use of applied WGS for food safety management saved them additional costs compared with older, less accurate and more time-intensive testing methods. NZFSSRC interviews with industry revealed that large food industries and companies are using WGS but for smaller companies the uptake is often constrained by costs and lack of knowledge (NZFSSRC, 2022b).

The costs for WGS consist of investments in laboratory and IT infrastructure, equipment and consumables, as well as the development of expertise in sequencing, bioinformatics, and microbial genomics. Regarding cost, Amézquita et al. (2020) stressed the importance of not comparing WGS with the standard microbiology detection and identification methods, as it is based on advanced molecular biology technology. A comparison with methods using the same technology such as genetically modified organisms and authenticity testing would put WGS in a more realistic price range (Amézquita et al., 2020).

Studies have shown mixed results regarding the cost of WGS implementation. For example, Klijn (2022) has suggested that the use of WGS may not always be cost-effective for firms over other available methods. However, the European Centre for Disease Prevention and Control (ECDP) (2015) showed that, for particular pathogens (e.g. E. coli and Campylobacter), WGS may be more time- and cost-effective than other available methods (ECDP, 2015).

Alleweldt et al. (2021a) examined the per-sample cost (in Euros) of WGS versus conventional methods for routine surveillance of foodborne pathogens in five countries, i.e Italy, Argentina, United States, Canada, and the United Kingdom, between 2016 and 2019. Results are shown in Table 4-2. The authors break down costs into multiple types for both conventional methods and WGS, showing the cost difference between the two. This shows that, on a per-sample basis, WGS is more expensive than conventional methods, with the relative cost of WGS over conventional methods ranging from 1.9 to 4.3 across a range of countries. In particular, the cost for equipment and consumables is much higher in WGS than conventional methods.

Table 4-2: Per-sample costs of WGS versus conventional methods by cost type (Italy, Argentina, US, Canada, UK) between 2016 and 2019 (€).

		Cost per sample				
		Italy	*Argentina*	*US*	*Canada*	*UK*
WGS						
Batch size for sample processing/ sequencing		24	12	24	32	Processing: 40 Sequencing: 96
Equipment		€163.49	€43.02	€29.53	€75.90	€35.23
Consumables		€165.37	€104.62	€4.40	€69.75	€53.92
Staff costs	Professionals	€52.35	€6.85	€20.58	€61.82	€28.30
	Technicians	€13.93	€0.00	€0.00	€7.89	€7.15
Other costs		€0.00	€0.00	€0.00	€0.00	€0.00
Total per sample cost WGS		€395.14	€154.49	€154.51	€215.36	€124.59
Conventional methods						
Equipment		€26.04	N/A	€5.84	€12.30	€7.11
Consumables		€20.17	N/A	€32.89	€34.95	€29.91
Staff costs	Professionals	€3.52	N/A	€42.43	€6.72	€2.92
	Technicians	€25.88	N/A	€0.00	€40.32	€3.85
Other costs		€16.27	N/A	N/A	€0.00	€1.67
Total per sample cost conventional methods		€91.87	€46.61	€81.16	€94.29	€65.46
Cost difference between WGS and conventional methods						
Additional cost WGS		€303.27	€107.88	€73.35	€121.07	€59.13
Quotient of WGS over conventional methods		4.3	3.3	1.9	2.3	1.9

Source: Alleweldt et al., 2021a.

Alleweldt et al. (2021a; 2021b) also determined the number of additional Salmonella cases that would need to be prevented to justify the additional cost of WGS compared with conventional methods. Results are shown in Table 4-3. The percentage of the total number of reported cases of salmonellosis that would need to be avoided to justify the higher cost for WGS compared with conventional methods varied between countries. An average of 0.7 per cent of reported cases of salmonellosis would need to be avoided to achieve this across all countries. The authors noted that the breakeven cost for WGS is relatively modest (Alleweldt et al., 2021a; 2021b).

Table 4-3: Break-even analysis, WGS versus conventional methods, foodborne Salmonella (Italy, Argentina, US, Canada, UK).

	Italy	*Argentina*	*US*	*Canada*	*UK*	*Average*
Cost per sample (WGS)	€395.14	€154.49	€154.51	€215.36	€124.59	€208.82
Cost per sample (conventional methods)	€91.87	€46.61	€81.16	€94.29	€65.46	€75.88
Differential cost of WGS compared with conventional methods	€303.27	€107.88	€73.35	€121.07	€59.13	€132.94
Number of samples per year (Salmonella)	110	128	1,010	8,273	10,147	3,934
Total additional costs per year due to WGS use	€33,360	€13,809	€74,084	€1,001,623	€599,992	€344,573
Average cost per reported case of salmonellosis	€12,124	€11,821	€13,225	€12,174	€12,401	€12,349
Number of reported cases of salmonellosis that need to be avoided to break even	2.8	1.2	5.6	82.3	48.3	28.0
Number of cases of salmonellosis reported annually	276	758	906	7,665	8,770	4,404
Percentage of total number of reported cases of salmonellosis that need to be avoided to break even	**1.0%**	**0.2%**	**0.6%**	**1.1%**	**0.6%**	**0.7%**

Source: Alleweldt et al., 2021a.

As previously discussed, Brown et al. (2021) estimated the total benefits of WGS source tracking in the prevention of three diseases in the US (*E. coli*, Salmonella and Listeria). Table 4-4 shows the estimated burden of illness averted for Listeria, E. coli and Salmonella through WGS use. The annual total estimated burden of illness averted has increased over time from US$3.24 million in 2014 to US$156.19 million in 2019. The greatest estimated burden of illness averted was shown for Listeria which comprised approximately 97 per cent of all estimated burden of illness averted in 2019 (Brown et al., 2021).

Table 4-4: Estimated burden of illness averted (Listeria, *E. coli*, Salmonella) in the US through WGS use, 2014-2019.

	Listeria	E. Coli	Salmonella	Annual Total	95% Confidence Interval
	Estimated Illnesses Averted				
2014	2	0	3	5	(2-8)
2015	13	7	20	40	(16-64)
2016	30	25	102	157	(62-252)
2017	51	63	190	304	(119-489)
2018	73	123	397	593	(223-954)
2019	91	210	675	976	(383-1,569)
	Monetised Illnesses Averted (US$ Millions)				
2014	3.22	0.00	0.01	3.24	(1.22-5.51)
2015	22.07	0.06	0.10	22.23	(8.36-37.87)
2016	49.48	0.23	0.50	50.21	(18.89-85.49)
2017	85.51	0.57	0.94	87.01	(37.72-148.09)
2018	121.56	1.12	1.96	124.64	(46.92-211.99)
2019	150.96	1.91	3.33	156.19	(58.83-265.47)

Source: Brown et al., 2021.

Brown et al. (2021) also estimated the potential burden of illness that could be averted if rates of under reporting and underdiagnosis of Listeria, *E. coli* and Salmonella are taken into account. This increased estimates significantly, as shown in Table 4-5. The total value of estimated burden of illness averted in 2019 shifts from US$156 to US$497 million when taking underdiagnosis and underreporting rates into account. This is an increase of 218 per cent. This significant reduction in social costs from foodborne illness shows the value in the deployment of WGS for foodborne illness detection and prevention.

Table 4-5: Estimated burden of illness averted (Listeria, *E. coli*, Salmonella) in the US through WGS use, with underreporting and underdiagnosis multipliers applied.

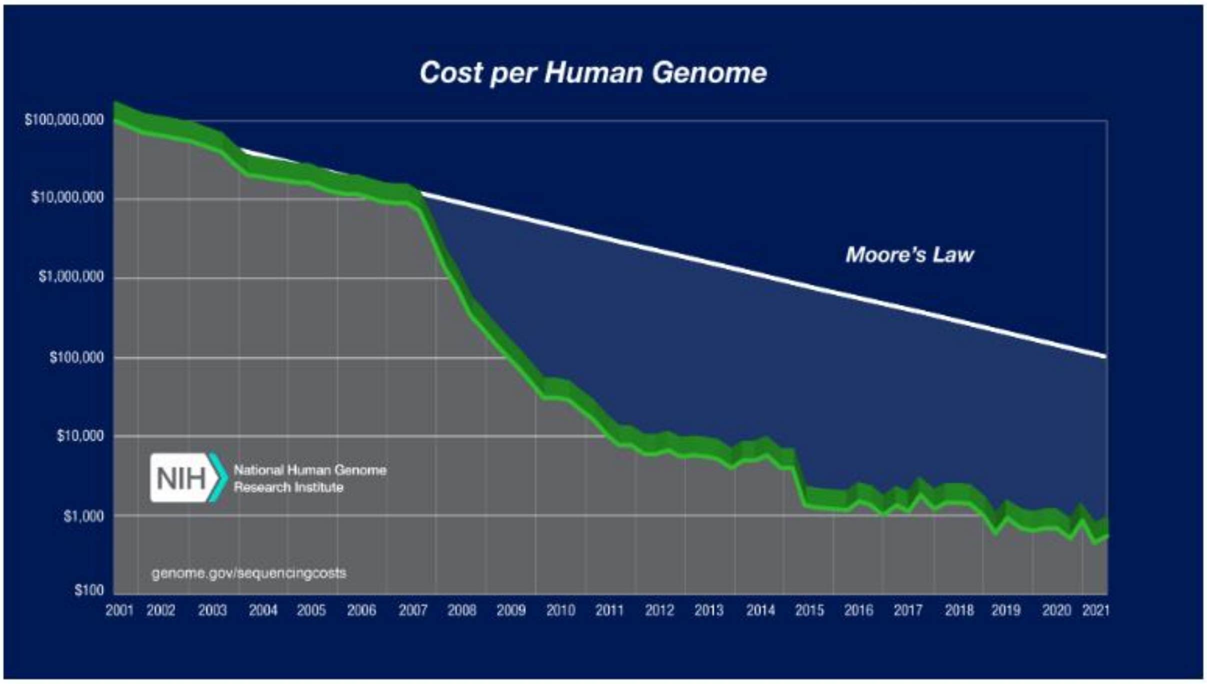
	Listeria	E. Coli	Salmonella	Annual Total	95% Confidence Interval
	Estimated Illnesses Averted				
2014	4	13	80	98	(37-166)
2015	31	185	574	789	(297-1,339)
2016	69	671	2,982	3,722	(1,398-6,339)
2017	119	1,670	5,577	7,366	(2,770-12,534)
2018	169	3,281	11,636	15,085	(5,670-25,683)
2019	210	5,592	19,792	25,595	(9,619-43,589)
	Monetised Illnesses Averted (US$ Millions)				
2014	7.43	0.12	0.39	7.94	(2.69-13.61)
2015	50.95	1.68	2.83	55.46	(20.79-94.89)
2016	114.23	6.13	14.69	135.04	(51.03-229.39)
2017	197.39	15.24	27.46	240.09	(90.87-406.78)
2018	280.62	29.94	57.30	367.86	(139.56-620.41)
2019	348.48	51.03	97.47	496.98	(188.62-835-92)

Source: Brown et al., 2021.

Hoelzer et al. (2018) estimated the cost of WGS in the case of *L. monocytogenes* surveillance at approximately US$100 per bacterial isolate. This correlates with estimates provided by NZFSSRC industry partners, who stated that "*with advances in sequencing technologies, the cost is now roughly equivalent to change[ing] the tyres on your car*". Hoelzer et al. (2018) further indicated that WGS in the US during years 1 and 2 had detected on average 3.5 outbreaks annually compared to an average annual outbreak detection rate of 0.3 over the 10 years prior to routine WGS use.

Figure 4-1 illustrates the decrease in WGS costs over the past two decades. The costs for WGS have fallen significantly in the past 20 years. In 2021, costs to sequence a human genome were below US$1,000. The graph also shows hypothetical data reflecting Moore's Law, which describes a long-term trend in the computer hardware industry that involves the doubling of 'computer power' every two years (NHI, 2021).

Figure 4-1: Cost per genome, 2001 – 2021, in US$.



Source: NHI, 2021.

After cost, there are other issues and barriers for the uptake of WGS by food industry. According to Diplock (2022), one of biggest challenges for WGS is in interpreting the rates and amount of genetic variation over time. Interpretation of WGS results requires expertise and is not straight forward. This was mentioned by industry participants in a workshop about the Listeria database facilitated by ESR and NZFSSRC. Participants pointed out that they need educating about the interpretation of WGS results and the benefits of WGS (NZFSSRC, 2021d).

Other concerns with the implementation and analysis of WGS for foodborne outbreak investigations include method standardisation. Currently, there is no global standard describing the methodology for the use of WGS in pathogen source tracking. Standardisation through, for example, the International Organization for Standardization (ISO) would be useful. ISO is imperative for accreditation, alignment of methodology, and ensuring results will be internationally recognised (Amézquita et al. 2020).

Diplock (2022) stressed that harmonisation and standardisation of WGS methods and interpretation across countries and sectors (human, animal, environmental, and food) is needed to allow data sharing and to ensure a consistent response. Diplock (2022) listed other concerns with the implementation of WGS for foodborne incidents, including consistency, political will, funding, and sharing of sensitive metadata, particularly with international partners (Diplock, 2022).

Also of concern is data confidentiality. Collection and testing of isolates provides large volumes of metadata that include confidential and sensitive data such as personal and health information, identities of food processors and other information, all of which require strong policies around the collection, storage, and sharing of information, particularly using large platforms which entails ethical and confidentiality issues (Diplock, 2022).

In 2019, a survey and workshop with representatives from 19 large, multi-national food companies was undertaken by Nestlé Research and Development to assess experiences on the use and implementation of WGS in the food industry. Participating companies included Danone, Fonterra, Kraft Heinz, Mars, Nestlé and Unilever. The participants agreed that WGS has been a game changer, and that the technology should be a permanent feature of food safety management systems. Participants highlighted the main benefit of the technology being its high discriminatory power to differentiate isolates. However, it was emphasised that a lack of knowledge to interpret results and the probability that not all safety specialists in the food industry are familiar with terminologies, methodologies and interpretation of WGS, hinder industry uptake of the technology. Participants stressed that they feel regulatory pressures to share WGS data. They also drew attention to the absence of a legal framework which creates a lack of clarity on data ownership (Klijn,2022; Amézquita et al., 2020).

4.4 Summary

WGS is suited for use in foodborne outbreaks, with particular relevance for national and international surveillance systems in support of harmonised food safety and public health. The technology has introduced a new level of precision to surveillance, leading to faster and more efficient decision-making in preparedness and responses to foodborne infections (Brown et al., 2019). However, the level of WGS implementation by the food industry varies. Some members have competencies covering all aspects of WGS analysis, while others are unfamiliar with the technology. In New Zealand, the establishment of the NZFSSRC has accelerated the development and use of WGS for food safety research and food safety risk management with many collaborative research projects finished or underway. One example is the WGS database for Listeria monocytogenes for New Zealand isolates (Food New Zealand, 2021).

The main benefits of the technology are its potential to speed up analysis, its specificity and its high discriminatory power. Additionally, WGS allows for rapid identification of outbreak sources, which allows outbreak intervention at an earlier stage and decreases the associated health and economic costs.

There are barriers and challenges that hinder industry uptake of the technology, including the high cost of implementation, followed by the complexity of analysis and interpretation of results. Other barriers include a lack of standardisation, confidentiality of data, issues of data storage and associated regulatory implications.

Chapter 5
Conclusion

The New Zealand Food Safety Science and Research Centre is a national, virtual scientific network of New Zealand's food safety researchers, hosted by Massey University and launched in 2016. The Centre synthesises input from industry, Māori, government and researchers to promote, coordinate and deliver food safety science and research for New Zealand. NZFSSRC is funded by government and industry. The Centre creates value for New Zealand society and the economy, predominantly through coordinating and conducting food safety research. In 2022, the NZFSSRC commissioned the Agribusiness and Economics Research Unit (AERU) at Lincoln University to quantify the value of the Centre's work and its impact more broadly in New Zealand.

This study has built on the literature review of the benefits of food safety undertaken by Guenther et al. (2022) as part of this research. Research methods included interviews with participants from the food industry and a desktop analysis to assess the economic contribution of NZFSSRC in three important food industries to New Zealand. Within each industry, a case study scenario for economic valuation of the Centre's involvement was constructed. These scenarios do not capture all of the benefits of the NZFSSRC, but they are representative examples that indicate its substantial impact. Thus, it must be stressed that this report offers a conservative analysis of the benefits of the Centre. Other identified case studies could not be quantified due to a lack of reliable data.

The case studies and their economic evaluation results were as follows:

1. **Dairy industry**

   - *Case Study: Avoiding costs from a hypothetical Cronobacter outbreak in New Zealand.*

     The establishment of the NZFSSRC contributes research and scientific expertise that supports the prevention of large-scale food safety outbreaks such as the Cronobacter incident in the USA in 2021/22. Calculations estimate a total cost saving through the work of the NZFSSRC of such an outbreak amounting to NZ$691 million (based on a one-in-ten years occurrence). If the outbreak was in 5 years' time, then the current value of savings would be NZ$541 million and **annual net present value savings of NZ$54 million.**

   - *Case Study: Avoiding dairy plant closure supported by Whole Genome Sequencing (WGS) arising from NZFSSRC research*.

     NZFSSRC WGS research allowed the isolation of a harmful pathogen found in a dairy processing plant. Only one dryer at the plant needed isolation. Based on this, the processing firm was able to simply remove the affected dryer from production at the plant, **saving NZ$100,000 in costs associated with plant closure and testing.**

- *Case Study*: *The prevention of a ban of whole milk powder (WMP) exports to the EU based on NZFSSRC advice to members of the New Zealand dairy sector on the likely shift in EU policy on maximum residue limits (MRLs) in cleaning agents.*

  NZFSSRC gave advice to dairy companies on EU law changes of the MRLs for cleaning agents in dairy processing plants. This prevented a ban of WMP exports to the EU with an estimated **cost saving ranging between NZ$5 million and NZ$39 million** assuming a 3 to 24 month transition period to a new cleaning agent for dairy processing plants.

2. **Kiwifruit industry**

- *Case Study: Impacts of NZFSSRC-led research on the potential transmission of COVID-19 via food or beverages including their packaging.*

  NZFSSRC research avoided an approximate 3 to 6 month export ban of kiwifruit into China. Calculations estimated a range of prevented economic cost of NZ$80 million (3 month export ban) to NZ$110 million (6 month export ban). In addition, this research also avoided the development of an unnecessary global (ISO) standard for food packaging. The calculations resulted in **NZ$9 million annual cost saving** from avoiding audit costs for **all** New Zealand food exporting companies. This value is significantly underestimated as it does not include any pre-audit costs for the companies or additional costs occurring during the audit process.

3. **Poultry industry**

- *Case Study: Impacts of the NZFSSRC-led longitudinal study on tracking Campylobacter in poultry flocks.*

  Calculations estimated **averted costs range from NZ$15 million to NZ$31 million per annum** by avoiding an extension of the processing stage by 2 to 4 hours for 1,121 cases annually.

In summary, the economic valuation of the case studies provides an estimate of the cost savings generated by specific research programmes. The results of these are summarised in Table 5-1. The estimated benefits are **extremely conservative**. The table also includes an estimate that the Centre's research avoided costs of NZ$1 million to prevent food safety outbreaks from the possible transmission of human diseases onto food (e.g. typhoid cases in the kiwifruit industry). Also, some estimates are not from annual incidents (e.g. dryer replacement and timely advice on changes of residue limits of cleaning agents in EU law) but assumes similar incidents happen every year, causing similar costs.

Additional cost savings which are not included in Table 5-1 are lawsuits and legal acts from food safety outbreaks. These can lead to significant costs for the responsible parties as shown by Fonterra's pay-out to Danone of €105 million (NZ$183 million) based on the WPC 80 incident in 2013. In addition, most interview participants mentioned food safety outbreaks could easily damage brand reputation with one participant stating this would be around NZ$2 billion. These indirect costs are often higher than the direct costs of the food safety incident. However, reputational and brand effects are almost impossible to measure.

Other cost savings were mentioned in discussion with participants. A company, for example, explained that a recent recall cost their company around NZ$50,000 to NZ$60,000 and caused market access issues and trade disruptions in export markets. NZFSSRC research, including of the use of WGS, will prevent these costs in the future.

The total cost saving in Table 5-1 amounts to NZ$164 million annually. This can be compared to the annual budgeted operating costs for the NZFSSRC of NZ$2.5 million from government and industry.

Table 5-1: Estimated cost savings through selected NZFSSRC-led research programmes.

Industry sector	Case	Estimated cost saving through NZFSSRC-led research, NZ$ million, per annum
Dairy	Hypothetical Cronobacter outbreak in NZ	54.0
	Dryer Replacement	0.1
	EU Cleaning Compound MRLs	4.8
Kiwifruit	Prevention of a COVID-19 related export ban of New Zealand kiwifruit to China	79.5
	Prevention of an unnecessary food packaging (ISO) Standard implementation for all New Zealand exporting firms	9.2
	Prevention of costs from fruit disposal, extended storage, delayed exports to avoid transmission of typhoid onto fruit	1.0
Poultry	Impact of the NZFSSRC-led longitudinal study on tracking Campylobacter in poultry flocks	15.4
TOTAL		**$164.0**

Note: Values are shown in 2021/2022 prices.

Further benefits from the NZFSSRC emerged from the stakeholder interviews. These are less tangible and difficult to quantify in monetary terms but are significant to NZFSSRC industry members. These identified benefits significantly contribute to the prevention or reduction of costs from food safety outbreaks.

The NZFSSRC:

- is a central point for food safety research and funding coordination.
- facilitates networking, relationship building and capability development through industry groups and taskforces.
- contributes to understanding the importance of food safety in the food system.
- has scientific credibility and integrity as an independent research centre that produces high quality research.

One observation arising from the interviews is the need for public-good research funding. The current NZFSSRC funding model requires industry to commit 60 per cent funding of the research undertaken by the Centre; hence research provided by the Centre is predominantly applied and of direct relevance to specific food industries. However, as mentioned in the interviews with industry and with the Centre itself, there is a need for public good research to undertake research independently of industry partners. This research would also extend across a wider range of areas of critical importance to the health and wellbeing of New Zealanders, including Māori. There is also a need for research on emerging issues, new technologies and for Māori industry and communities, for example: preparing food industries for new outbreaks; responding to the impacts of climate change on food safety; and incorporating mātauranga Māori into the research.

Whole Genome Sequencing

Whole Genome Sequencing for food safety detection and surveillance is a key research capability developed and facilitated in New Zealand by the NZFSSRC. Currently, WGS provides the highest possible microbial subtyping resolution available to public health authorities for the surveillance of, and response to, foodborne diseases. The establishment of the NZFSSRC has accelerated the development and widespread use of WGS for food safety research in New Zealand. Almost all food industries have been involved in a collaborative research project with NZFSSRC involving WGS of pathogens. The main benefits of the technology are its efficiency, specificity and high discriminatory power. Additionally, WGS allows for quick identification of outbreak sources, which means outbreak intervention at an earlier stage to decrease the associated health and economic costs.

Conclusion

The NZFSSRC creates considerable value for New Zealand by providing and coordinating food safety research and expert advice. The Centre also creates networks nationally and internationally by facilitating relationships between government, industry, Māori, and researchers. These relationships are key to generating positive outcomes for food safety, public health and maintaining New Zealand's reputation as a producer of safe food.

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