

## **Risk Profile update: Non-typhoidal *Salmonella* in animal feed and feed components**

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## Scientific Interpretative Summary

This Scientific Interpretive Summary (SIS) is prepared by New Zealand Food Safety (NZFS) risk assessors to provide context to the following report for Ministry for Primary Industry (MPI) risk managers and external readers.

### **NZFSSRC406922-M12/FW22038: Risk Profile update: Non-typhoidal *Salmonella* in animal feed and feed components**

The detection of a strain of *Salmonella* Enteritidis through the routine National Microbiological Database (NMD) monitoring programme in March 2021 was the first reported incidence in New Zealand commercial poultry flocks. The strain was linked by whole genome sequencing (WGS) to human cases, including an outbreak dating back to December 2019, with a seemingly higher rate of hospitalisation than other *Salmonella* strains. The strain detected in poultry and causing illness in people was determined to be a potentially transovarian strain phage type (PT) 8, which could have particularly concerning consequences for poultry farmers. While the origin of the outbreak strain has not been determined, it is possible that, despite risk mitigation measures being in place, the strain was introduced to New Zealand via poultry feed or feed ingredients.

This Risk Profile is an update to the 2011 Risk Profile for *Salmonella* in feed, published prior to *Salmonella* Enteritidis detection in commercial poultry. While the emergence of a *Salmonella* Enteritidis strain in poultry has not yet had a material impact on overall salmonellosis case numbers in New Zealand, this Risk Profile update set out to help understand whether the indirect risk to public health from contamination of feed by *Salmonella* had changed since the previous risk profile. This Risk Profile considers non-pasture and non-forage-based feeds (e.g., grains, blood and bone meal) intended as food for food-producing animals. Forage and pasture feeds used as ingredients of compound feed (i.e., formulated to meet specific nutritional requirements) are also within scope.

In New Zealand, the poultry sector is the biggest user of compound feed, followed by pigs. Farmed pigs and poultry require a year-round supply of harvested and/or processed feed that is more highly digestible than pasture. The main ruminant livestock species (cattle, sheep, goats, and deer) are raised on pasture systems. Supplementary feeds for these sectors are used during winter or drought conditions, although there is increasing use in the dairy sector. *Salmonella* contamination of animal feed can occur from contaminated source materials, contaminated dust, or raw meal material post-manufacture, during transport to the farm, or during storage or use at the farm. *Salmonella* will not grow in dry animal feed but can survive and persist for extended periods of time.

The risk of *Salmonella* being introduced to food producing animals by contaminated feed was deemed to remain low based on the relatively low incidence of *Salmonella* detected through industry testing of finished feed and feed components intended for poultry. Feed that is not heat-treated or is produced by individual farms for their own purposes, which receives less processing, might carry a higher risk for *Salmonella* contamination and consequently, an increased exposure risk to animals that consume it.

Human salmonellosis is not likely to be attributed to a feed source, particularly if the serotypes are already common in the animal and human population. Serotypes commonly isolated from feed ingredients and finished feed are observed from both food-producing animals and human cases of salmonellosis in New Zealand. *Salmonella* present in animal feed presents an indirect risk to consumers of animal products from livestock receiving contaminated feed. While this report concludes that there is insufficient evidence to quantitatively determine the level of risk, the risk remains low to negligible where feed and feed components are sourced from suppliers with effective contamination controls.

## **RISK PROFILE UPDATE: *SALMONELLA* (NON-TYPHOIDAL) IN ANIMAL FEED AND FEED COMPONENTS**

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# ABBREVIATIONS

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aOR	adjusted odds ratio
$a_w$	water activity
APHA	Animal and Plant Health Agency
BSE	bovine spongiform encephalopathy
CFU	colony forming units
CI	confidence interval
CIDT	culture-independent diagnostic tests
CLSI	Clinical and Laboratory Standards Institute
DALY	disability adjusted life years
DDGS	Distiller's Dried Grains with Solubles
DEFRA	Department for Environment Food & Rural Affairs of the United Kingdom
DHB	District Health Board
DT	definitive phage type
D-value	The time of exposure at a given temperature/treatment that results in a 90% (a decimal or 1 log <sub>10</sub> cycle) reduction in the number of viable organisms
ECS	Emergency Control Scheme
EFSA	European Food Safety Authority
ERL	Enteric Reference Laboratory (at ESR)
ESR	Institute of Environmental Science and Research Limited
EU	European Union
EUCAST	European Committee on Antimicrobial Susceptibility Testing
F <sub>0</sub>	The measure of the amount of lethal heat which results from a specified thermal process, and is the lethal effect equivalent to the number of minutes at 121.1°C when assuming instantaneous heating and cooling and a z-value of 10°C
HACCP	Hazard Analysis and Critical Control Point
MIRINZ	Meat Industry Research Institute of New Zealand
MLST	multilocus sequence type
MLVA	Multiple-locus variable-number tandem repeat analysis
MPI	Ministry for Primary Industries
MPN	Most probable number
NMD	National Microbiological Database

NZFMA	New Zealand Feed Manufacturers Association
NZFS	New Zealand Food Safety
OECD	Organisation for Economic Cooperation and Development
OR	Odds ratio
PBS	Phosphate buffered saline
PCR	polymerase chain reaction
PFGE	pulsed field gel electrophoresis
PIANZ	Poultry Industry Association of New Zealand
PKE	Palm kernel expeller/extract
PT	provisional phage type
RDNC	reaction does not conform
RMP	Risk Management Programme
RMQ	Risk Management Question
SE_2019_C_01	S. Enteritidis outbreak strain designation
SNP	single nucleotide polymorphism
ST	sequence type (abbreviated form of MLST)
STEC	Shiga toxigenic <i>Escherichia coli</i>
UK	United Kingdom
US	United States of America
US FDA	United States Food and Drug Administration
USDA	United States Department of Agriculture
VBNC	viable but non-culturable
WGS	whole genome sequencing
WHO	World Health Organization
Z-value	The temperature change (in degrees) required to reduce or increase the D-value by one decimal

# SUMMARY

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The purpose of a Risk Profile is to provide information relevant to a food/hazard combination so that risk managers can make decisions and, if necessary, take further action. Risk Profiles include elements of a qualitative risk assessment, as well as providing information relevant to risk management. This Risk Profile concerns non-typhoidal *Salmonella* in animal feed and feed components, with a focus on feeds that are not pasture or fodder-based; the majority of data identified relates to compound feed and materials. Feeds intended for livestock and poultry that are farmed commercially in New Zealand are considered due to the potential for *Salmonella* to be transmitted to humans via the consumption of contaminated animal products. This is an update of a Risk Profile published in 2011 (Cressey et al. 2011). The key findings from that report were that:

- The most common *Salmonella* serotype in finished animal feed in New Zealand at that time (*S. Tennessee*), based on industry data, occurred infrequently amongst human cases, arguing against animal feed as a major source of human salmonellosis in New Zealand.
- Control of *Salmonella* contamination in the animal feed industry is complicated by the diversity of products, with some receiving heat treatment and some not. Further complication is introduced through the wide diversity of materials that may be used for, or in, animal feed. Information from New Zealand and overseas suggests that none of these source materials can be assumed to be free of *Salmonella*.

In New Zealand, the main ruminant livestock species (cattle, sheep, goats and deer) are raised on pasture systems. Supplementary feeds for these sectors are used during winter or drought conditions, although there is increasing use in the dairy sector. Pigs and poultry are monogastric species and require a year-round supply of harvested and/or processed feed that is more highly digestible than pasture. The poultry sector is the biggest user of compound feed, followed by pigs, dairy cattle and calves. There was approximately 1.1 million tonnes of compound feed produced in 2022. Production has increased 22% since 2011, which reflects increases in sector size and requirements for the poultry, dairy, calf and other ruminant sectors. Approximately 60% of the raw materials used in the production of animal feed in New Zealand are imported, which mainly includes grain and plant protein materials. Animal protein and extract materials are primarily produced domestically.

*Salmonella* contamination of animal feed can occur from contaminated source materials, contaminated dust or raw meal material post-manufacture, during transport to the farm, or during storage or use at the farm. *Salmonella* will not grow in dry animal feed, but can survive and persist for extended periods of time, which is influenced by the initial level of *Salmonella* contamination, serotype present, feed type, and storage conditions. In general, cooler temperatures and a lower water activity promote *Salmonella* survival. *Salmonella* will also not grow in the feed mill environment unless moisture levels are elevated. Biofilm formation can promote *Salmonella* persistence and protect against environmental stresses such as disinfection. Heat treatment (70-90°C) is the most effective method used during feed manufacture to inactivate pathogens including *Salmonella*, although not all manufactured feed undergoes heat treatment. Thermal tolerance of *Salmonella* in animal feed is influenced by the serotype present, and the particle size and composition of the feed; for example, the fat content, moisture levels and acidity. Based on published data and models, the optimum conditions achieved in New Zealand feed mills (90°C for 90 seconds) would be expected to

inactivate low levels of contamination by even thermally tolerant strains of *Salmonella* that might be present.

In New Zealand, *Salmonella* has been detected in feed materials and finished feed for poultry and other food producing animals in all years since the 2011 Risk Profile. For poultry feed materials and feed, prevalence is typically low (1.0% of the 45,438 samples tested from 2011 to 2022). Certain serotypes are commonly observed as contaminants of animal feed and feed materials in New Zealand; the top five serotypes from 2011 to 2022 were *S. Infantis* (189 isolates) *S. Mbandaka* (171 isolates), *S. Agona* (109 isolates), *S. Typhimurium* (96 isolates), and *S. Havana* (79 isolates). Most of the serotypes detected in feed from 2011 to 2022 were also detected in feed for the period assessed in the 2011 Risk Profile. Serotypes reported in New Zealand feed and feed materials were also common from feed and ingredients in other countries.

The most common serotypes present in feed materials and finished feed in New Zealand were also commonly isolated from food-producing animals and their meat. Product from food-producing animals may also be used in the production of feed (noting that poultry meal is not fed to poultry and ruminant meal is not fed to ruminant animals). Therefore, the direction of transmission could occur from animal-to-feed or from feed-to-animal, and there are other transmission pathways by which infection of animals and contamination of feed can occur. Internationally, serotypes that are common contaminants of animal feed are more commonly observed in poultry flocks than other food animal sectors (although there are more surveillance programmes for *Salmonella* in poultry to inform exposure than for other sectors). Although this evidence is circumstantial, investigations have also identified incidences whereby *Salmonella* contamination of animal feed has been linked to subsequent colonisation of poultry, pigs and cattle.

Exposure to humans of animal food product that might be contaminated with *Salmonella* is in part defined by the level of contamination, how the product is cooked and handled to mitigate the risk, together with the volume consumed. There has been a 9.4% increase in meat consumption in New Zealand from 2011 and 2022. Although there have been decreases in the consumption of beef/veal (31.2% reduction) and mutton/lamb (40.7% reduction), these were more than offset by the increases in the consumption of poultry meat (35.9% increase) and pork (19.9% increase). Egg consumption has fluctuated since 2010. Of these animal products, eggs are most likely to be consumed raw or undercooked.

The yearly incidence of human salmonellosis in New Zealand was relatively static for the period covered by this Risk Profile (from 2011 to 2022). However, there were fewer notifications during 2020 to 2022 which could be attributed to the impact of the public health response to the COVID-19 pandemic. Just a single death associated with salmonellosis occurred in New Zealand during this time (in 2017). Antimicrobial resistance remains relatively low among non-typhoidal *Salmonella* isolated from human, animal and environmental samples in New Zealand. *S. Typhimurium* was the most frequently isolated serotype from human salmonellosis cases in New Zealand, followed by *S. Enteritidis* (39.3% and 11.8% of cases where a serotype was identified, respectively, for the period 2011 to 2022). The most common serotypes from animal feed were also observed among human salmonellosis cases, although human cases of *S. Mbandaka* and *S. Havana* were less common. The reported number of salmonellosis outbreaks each year was similar between the periods 2005 to 2010 (8 to 26) and 2011 to 2022 (5 to 27). Although outbreaks over the 2011 to 2022 period occurred for which the consumption of animal product was implicated as the suspected source, none were linked to transmission through the food chain arising from contaminated livestock feed.

This Risk Profile sought to answer the following specific Risk Management Questions (RMQs), with a focus on information that has become available since the 2011 Risk Profile was produced:

- **RMQ1:** What is the risk of introduction of *Salmonella* into food-producing animals (poultry broilers and layers, cattle, sheep, pigs) by contamination of feed?

There are a range of systems in place in New Zealand to control microbiological hazards such as *Salmonella* in feed materials and finished feed, including import requirements for feed materials, legislative controls, codes of practice, and heat treatment steps during feed manufacture. Despite these controls, *Salmonella* contamination of feed materials (which might be fed directly to animals) and finished animal feed is sometimes detected in New Zealand. Therefore, animals are likely to be exposed to *Salmonella* through consumption of the contaminated feed, which presents a risk of them becoming colonised. While the colonisation of animals with *Salmonella* through the consumption of contaminated feed has been demonstrated, there is insufficient information on the prevalence and levels of *Salmonella* contamination of feed in New Zealand and the associated dose-response relationships for various animal species to be able to accurately estimate the extent of the risk. However, the risk is likely to be low based on the low incidence of *Salmonella* contamination of feed detected. Feed that is not heat-treated, or is produced by individual farms for their own purposes, which receives less processing, might carry a higher risk for *Salmonella* contamination and consequently, an increased exposure risk to animals that consume it.

- **RMQ2:** Considering the detection of *Salmonella* Enteritidis in chicken products and on farms, has the risk of introduction of *Salmonella* into food producing animals changed since the 2011 Risk Profile update?

The first detection of *S. Enteritidis* ST11, DT8 in New Zealand poultry was from a processed poultry carcass during 2021, followed by detection in hatcheries and poultry sheds (from both layer and broiler flocks). The risk of transmission of *S. Enteritidis* from positive chicken flocks into food-producing animals via feed is considered to be very low. Material from *S. Enteritidis*-positive flocks may have been sent for rendering for use in animal feed. However, thermal processes during rendering are required to be validated to show that *S. Enteritidis* contamination is reduced to an appropriate level. Furthermore, feed pelleting processes should inactivate most or all *S. Enteritidis* in the event that there are trace levels of contamination of rendered product entering the feed mill. This serotype is not commonly associated with animal feed or feed mill environments internationally. No poultry meal was used for food-producing animal feed in New Zealand during 2021 and 2022, and prior to 2021, its use was limited to home-milled pig feed. This serotype has not been detected in feed for the period assessed (2011-2022) and similarly, was not reported in the 2011 Risk Profile. Although incidences of transmission of the outbreak strain to other animal species have occurred, there is no evidence that animals were infected via the feed transmission route.

- **RMQ3:** What is the flow-on effect for human exposure?

The potential for human cases of salmonellosis to result from exposure to foods arising from animals colonised with *Salmonella* is well-known, and it follows that any feed-borne transmission to food producing animals could result in flow-through transmission to humans. Given the intensive nature of poultry and swine rearing (which allows for transmission of *Salmonella* between animals in a flock/herd) and their dependence on compound feed, combined with the increasing consumption of poultry and pork products by New Zealanders, there is potential for an on-farm contamination event to be magnified through the food chain.

Only one outbreak of human salmonellosis due to transmission from animal feed via animal food product to humans has been reported in New Zealand. Internationally, only a limited number have been reported, which were via poultry and swine feed and food chains. However, human salmonellosis is not likely to be attributed to a feed source, particularly if the serotypes are already common in the animal and human population. Serotypes commonly isolated from feed ingredients and finished feed are observed from both food-producing animals and human cases of salmonellosis in New Zealand. Therefore, there is sufficient evidence that *Salmonella* present in animal feed presents a risk to consumers of animal products from livestock receiving contaminated feed, but there is insufficient evidence to quantitatively determine the level of risk.

Important data gaps for addressing the RMQs included:

- Prevalence and numbers of *Salmonella* in feed and feed components in New Zealand;
- Prevalence of *Salmonella* serotypes associated with the primary production of food-producing animals, and on meat of food product at retail in New Zealand;
- Data from finer typing (such as whole-genome sequencing) of *Salmonella* isolates from feed, food-producing animals, food produced from those animals, and humans, that would allow identification of linkages and possible transmission routes.

# 1 INTRODUCTION

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The purpose of a Risk Profile is to provide information relevant to a food/hazard combination so that risk managers can make decisions and, if necessary, take further action. Risk Profiles are a preliminary risk management activity, and part of the Risk Management Framework<sup>1</sup> approach taken by New Zealand Food Safety (NZFS), a business unit of the Ministry for Primary Industries (MPI). The Framework consists of a four-step process:

- Preliminary risk management activities;
- Identification and selection of risk management options;
- Implementation of control measures; and
- Monitoring and review.

This Risk Profile considers non-typhoidal *Salmonella* in animal feed and feed components. This is an update of a 2011 Risk Profile (Cressey et al. 2011). As such, this is not a stand-alone document.

The hazard considered in this Risk Profile is the group of non-typhoidal serotypes of the bacteria *Salmonella enterica* subspecies *enterica*. Typhoidal *Salmonella* serotypes *S. enterica* subspecies *enterica* (S.) Typhi, *S. Paratyphi* A, B, and C, and *S. Sendai* are not considered by this Risk Profile as they are restricted to human hosts (Feng et al. 2019, Gal-Mor 2019). The exception is *S. Paratyphi* B variant Java<sup>2</sup>, which is considered because it is a dominant poultry serotype overseas (van Pelt et al. 2003, Castellanos et al. 2020).

The food considered in this Risk Profile is animal feed, with particular attention to the potential for *Salmonella* in animal feed to be transmitted to humans via consumption of contaminated animal material. The focus is on feed for the main mammalian livestock (dairy cows, beef cattle, sheep, deer, goats and pigs) and poultry species that are farmed commercially in New Zealand. Food for companion animals (pet food) and for farmed aquatic species are not within scope. For the purpose of this Risk Profile, animal feed will mainly refer to manufactured compound feed. However, recent years have seen a diversification in feed ingredients and feeding practices in New Zealand's production animal industries. For this reason, the Risk Profile will consider a wider definition of feed, to include all non-pasture and non-forage feeds.

This Risk Profile seeks to answer the following specific Risk Management Questions (RMQs), with a focus on information that has become available since the 2011 Risk Profile was produced:

- **RMQ1:** What is the risk of introduction of *Salmonella* into food-producing animals (poultry broilers and layers, cattle, sheep, pigs) by contamination of feed?
- **RMQ2:** Considering the detection of *Salmonella* Enteritidis in chicken products and on farms, has the risk of introduction of *Salmonella* into food producing animals changed since the 2011 Risk Profile update?
- **RMQ3:** What is the flow-on effect for human exposure?

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<sup>1</sup> <https://www.mpi.govt.nz/dmsdocument/22000/send>, accessed 27 October 2022

<sup>2</sup> *S. Java* is also known more recently as *S. enterica* subsp. *enterica* serovar *Paratyphi* B var. *d-Tartrate*<sup>+</sup>

## 2 HAZARD AND FOOD

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### 2.1 THE PATHOGEN: NON-TYPHOIDAL *SALMONELLA*

#### Key findings

- All *Salmonella* serotypes are considered potentially pathogenic to humans. Pathogenicity varies between and within serotypes.
- The primary sources of *Salmonella* are the gastrointestinal tracts of humans and animals, via excretion into the environment.
- Red and white meats, meat products, unpasteurised milk, raw milk cheeses and eggs are the foods most often implicated as causes of human salmonellosis, although a wide variety of other foods have also been associated with outbreaks, including dry foods.

#### 2.1.1 *Salmonella* species (spp.)

This group of bacteria is comprised of two species: *Salmonella enterica*, which is divided into six subspecies (*enterica*, *salamae*, *arizonae*, *diarizonae*, *houtenae* and *indica*), and *Salmonella bongori* (Grimont and Weill 2007). Most pathogenic isolates from humans and other mammals belong to *S. enterica* subspecies *enterica*. Other *S. enterica* subspecies and *S. bongori* are more common in cold blooded animals and the environment and are of lower pathogenicity to humans and livestock (Brenner et al. 2000, Lamas et al. 2018). In addition, some *S. enterica* subspecies *enterica* serotypes are well adapted to specific animals while others (e.g. *S. Typhimurium*) have a wide host range (Jajere 2019).

*Salmonella* are primarily divided into types using serological identification of somatic (O), flagella (H), and capsular (K) antigens, which are named according to the Kaufmann-White scheme (last updated in 2007) (Grimont and Weill 2007). There are more than 2,500 different *Salmonella* serotypes (also called serovars), and of these over 1,500 have been identified in the *S. enterica* subspecies *enterica* group. For designating the serotype, the subspecies does not need to be indicated, but it has been recommended that the abbreviation (S.) of the genus name (*Salmonella*) should not stand alone without being followed by a specific epithet (*S. enterica*) (Grimont and Weill 2007). However, for practical purposes, the approach taken by this report, and commonly used in literature, involved the *Salmonella* serotype name following S. as the abbreviation used for *Salmonella enterica*. The serotype is capitalised and non-italicised; for example, *Salmonella enterica* subsp. *enterica* serotype Enteritidis becomes *Salmonella* Enteritidis (or *S. Enteritidis*) (Brenner et al. 2000).

Previous Risk Profiles have referred to “*Salmonella* spp.”. Technically, spp. refers to multiple *Salmonella* species, and for the large part, we are only referring to the single subspecies (*S. enterica* subspecies *enterica*), which is defined in the previous paragraph. As such, in this document “*Salmonella*” is used throughout, rather than “*Salmonella* spp.”.

*Salmonella* can be further subtyped by measuring susceptibility to a panel of bacteriophages. These types are denoted as provisional phage type (PT) or definitive phage type (DT) numbers; the term DT is used in this document. Phage typing does not provide information on genotypic relationships and has been phased out in favour of more informative molecular analyses. The production of phages for *Salmonella* phage typing has now been discontinued internationally.

Since November 2019, whole genome sequence (WGS)-based typing methods have replaced phage typing for typing of *S. Enteritidis* and *S. Typhimurium* isolates in New Zealand. These

isolates are now reported as the serotype and an Achtman 7-gene multilocus sequence type (MLST; or more simply, sequence type; ST) is now reported (Achtman et al. 2012). Unlike phage typing, the ST enables isolates to be clustered into evolutionary groupings. There is no correlation between phage type and sequence type because closely related *Salmonella* strains might have different phage types, and not all strains of the same phage type are closely related (Pang et al. 2012, Mohammed and Cormican 2015, Kingsbury and Soboleva 2019). WGS data can be used to investigate the relatedness of strains of the same serotype and ST by Single Nucleotide Polymorphism (SNP) analysis. This method is now used in New Zealand and internationally for salmonellosis outbreak or cluster investigations. Further information on *Salmonella* typing, is included in Appendix B.3.

### 2.1.2 Sources of *Salmonella*

The primary sources of *Salmonella* are the gastrointestinal tracts of humans and animals, and their excrement results in the pathogen being widespread in the environment (Bell and Kyriakides 2002).

Since the 2011 Risk Profile (Cressey et al. 2011), the main change to the primary sources and transmission of *Salmonella* within New Zealand is the detection of *S. Enteritidis* in New Zealand poultry flocks during 2021.

Humans: Person-to-person transmission of *Salmonella* is well recognised, and secondary transmission of *Salmonella* in outbreaks has been demonstrated (Loewenstein 1975). Carriage in faeces in convalescent cases can be quite substantial with numbers approximating  $10^6$ - $10^7$  *Salmonella* cells/g faeces persisting for up to 10 days after initial diagnosis. Reduction in numbers with time is variable; most people will have counts of less than 100 *Salmonella* cells/g faeces after 35 to 40 days, but a count of  $6 \times 10^3$ /g has been recorded in one patient 48 days post-illness (Pether and Scott 1982). In New Zealand, other gastrointestinal diseases such as cryptosporidiosis, giardiasis and shigellosis are more strongly associated with person-to-person transmission than salmonellosis, but person-to-person risk factors are commonly cited in outbreak reports (Adlam et al. 2010). Asymptomatic carriage may also occur, and asymptomatic food handlers have been responsible for an outbreak of hospital-acquired infection (Dryden 1994) as well as an outbreak in a catering establishment (Stein-Zamir et al. 2009). An Australian study found a prevalence of 0.4% in stools from 1,091 asymptomatic people (Hellard et al. 2000).

Animals: *Salmonella* can be found in mammals, fish, reptiles, amphibians, insects and birds. Most *Salmonella* colonisations in animals produce no clinical signs. Some serotypes are largely confined to particular animal reservoirs causing both systemic and enteric disease, for example *S. Choleraesuis* is mostly host-restricted to pigs (Allison et al. 1969, Uzzau et al. 2000, Jajere 2019). Other serotypes such as *S. Typhimurium* are considered to have a broad host range because they are associated with intestinal colonisation and sometimes infections in a wide range of animal species (Paulin et al. 2002). However, variants within the *S. Typhimurium* serotype can differ in their host range and their degree of host adaptation (Rabsch et al. 2002). Both plant and animal product-based animal feed ingredients may be contaminated with *Salmonella*, serving as a source for animal colonisation. Sick animals have been the source of sporadic human salmonellosis cases (Adlam et al. 2010).

Food: *Salmonella* is a serious cause of foodborne illness worldwide. Foods and ingredients become contaminated through contact with faecal material, either directly or via environmental sources (for example, water and soil). Based on outbreak data, the foods most commonly implicated as sources are red and white meats, meat products, unpasteurised milk, cheese

and eggs (Jay et al. 2003, Chanamé Pinedo et al. 2022). Globally, *S. Typhimurium* has been found in a wide range of foods produced from animals, while *S. Enteritidis* tends to be associated with poultry products and *S. Anatum* with beef products (Ferrari et al. 2019).

In Australia, *S. Typhimurium* is the most commonly identified serotype in foodborne salmonellosis outbreaks; these outbreaks are most frequently associated with the consumption of raw or undercooked eggs, although poultry meat is also often implicated (The OzFoodNet Working Group 2022). *S. Enteritidis* can colonise the reproductive organs of hens and contaminate eggs prior to shell formation (transovarian transmission). This contamination and the associated potential for the bacteria to replicate and reach high numbers in the egg contents means that it poses a greater risk than other serotypes. In Europe, *S. Enteritidis* is the most common serotype found in layer flocks (and the second most common in broiler flocks), and continues to be the most common serotype in outbreaks, followed by *S. Typhimurium* (European Food Safety Authority and European Centre for Disease Prevention and Control 2022). The foods implicated most often in salmonellosis outbreaks occurring in Europe are eggs and egg products, as well as mixed foods (meals composed of various ingredients), and to a lesser extent poultry meat (De Knecht et al. 2015, European Food Safety Authority and European Centre for Disease Prevention and Control 2022). In contrast, New Zealand has a very low reported incidence of egg-associated salmonellosis, and *S. Enteritidis* was not detected in New Zealand poultry until 2021 (Section 4.2.6) (Ministry for Primary Industries Biosecurity Science, Food Science & Risk Assessment Directorate 2015, Kingsbury et al. 2019, Kingsbury 2023b).

*Salmonella* can survive in foods with low water activity ( $a_w$ ) (Finn et al. 2013), and outbreaks have occurred in New Zealand and internationally from *Salmonella*-contaminated flour and tahini (a product made from crushed sesame seeds) (Unicomb et al. 2005, McCallum et al. 2013, Paine et al. 2014). Outbreaks due to contamination of sprouts have also been implicated in recent New Zealand salmonellosis (Pattis et al. 2022). A wide variety of other foods have also been associated with salmonellosis outbreaks such as seafood (shellfish, salmon), nuts and nut products (desiccated coconut, peanut butter), cereal and cereal products (barley, cereal powder), spices (white and black pepper, paprika), oilseeds and oilseed products (cottonseed, soybean sauce, sesame seeds), vegetables (watercress, tomatoes, lettuce, potato and other salads), fruit and fruit products (watermelon, melon, cider) and other miscellaneous products (chocolate, cocoa powder, dried yeast, candy).

Environment: *Salmonella* in sewage effluents or animal faeces can contaminate pasture, soil and water. These bacteria do not usually multiply to a large extent in soil and waters (this will depend on other growth factors and conditions present) but may survive for long periods, including in dry environments (Bell and Kyriakides 2002, Haysom and Sharp 2003). *Salmonella* have been detected in surface waters in New Zealand (Till et al. 2008, Leonard et al. 2020). These bacteria can be dispersed in dust and aerosols generated during animal handling and processing, or by wind, water, wildlife and insects in the environment.

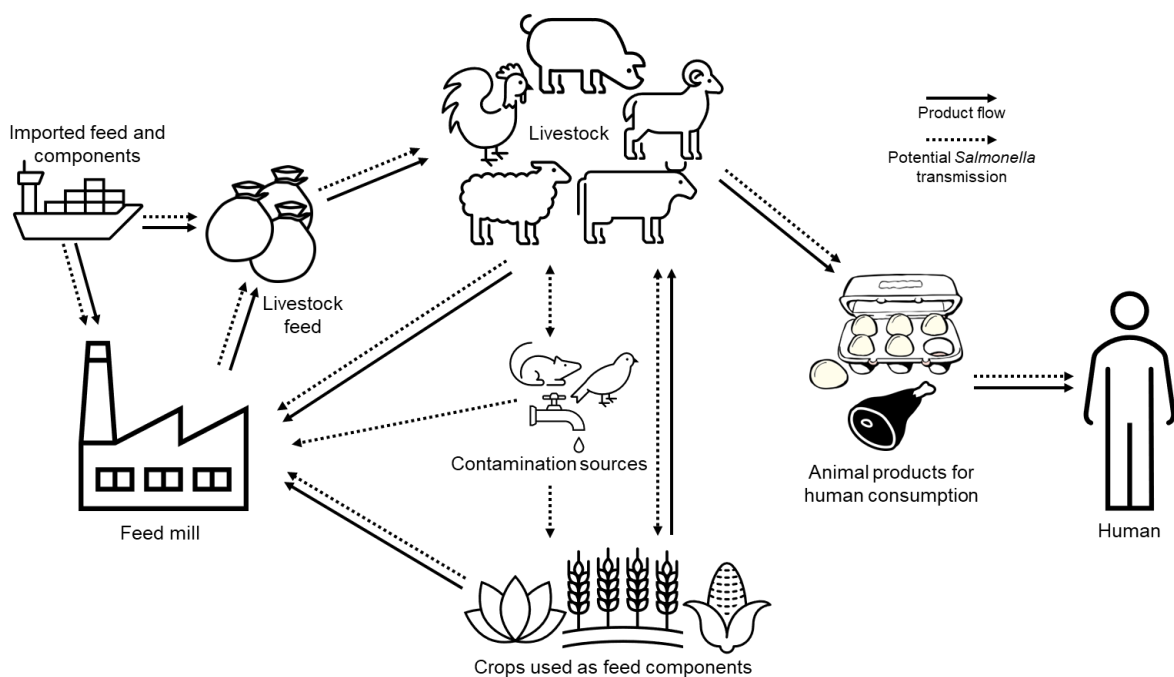
Transmission routes: *Salmonella* may be transmitted to humans via person-to-person transmission, contaminated food or water, animal contact or from a contaminated environment. A review of non-typhoidal salmonellosis sporadic cases and outbreaks in New Zealand indicated that the important pathways for *Salmonella* infection are consumption of contaminated food, consumption of untreated drinking water and contact with sick animals (King et al. 2011a).

## 2.2 THE FOOD: ANIMAL FEED AND FEED COMPONENTS

### Key findings

- In New Zealand, the main ruminant livestock species (cattle, sheep, goats and deer) are raised on pasture systems. Supplementary feeds for these sectors are mostly used during winter or drought conditions, although there is increasing use in the dairy sector due to intensification and improved production. Pigs and poultry are monogastric species that require a year-round supply of harvested and/or processed.
- The highest use of non-pasture supplementary feed is by the dairy cattle sector, while the poultry sector is the biggest user of compound feed. There were approximately 1.1 million tonnes of compound feed produced in 2022. Production has increased 22% since 2011, which reflects increases in sector size and requirements for the poultry, dairy, calf and other ruminant sectors.
- Approximately 60% of the raw materials used in the production of animal feed in New Zealand is imported, with imported materials mainly from the grain and plant protein categories. Additional imported material is direct-fed to animals. Animal product ingredients are primarily produced domestically.

It should be noted that this Risk Profile differs from others produced by ESR, as the ‘food’ that is the subject of the Risk Profile is not a human food. Instead it is animal food, conventionally referred to as feed, as well as the component materials used in the production of formulated feed. Food-producing animals are major reservoirs for many disease-causing microorganisms of importance to human health (pathogens), including serotypes of *Salmonella* (Crump et al. 2002). Pathogens can be acquired through ingestion. Therefore, contaminated animal feed can contribute to colonisation and, in some cases, infection of food-producing animals with *Salmonella* and other pathogens. The transmission pathways considered in this Risk Profile are depicted in Figure 1.



**Figure 1. Potential sources and transmission routes of *Salmonella* through the animal feed supply chain.**

In New Zealand, the main large animal food-producing species (cattle, sheep, goats and deer) are generally raised on pasture systems, typically perennial grasses and legumes (including hay and pasture silage), with supplementary feeds (for example, forage crops and food by-products) used during winter or drought conditions (Wedderburn et al. 2020). Some operations, such as some dairy goat farms, are housed and fed by pasture or crops through cut-and-carry. There has been an increase in the use of non-pasture feed for dairy cattle as a result of higher stocking rates and to support increased milk production (DairyNZ 2016).

For the purpose of this Risk Profile, animal feed will mainly refer to manufactured compound feed and feed materials, many of which may also be direct-fed. However, recent years have seen a diversification in feed ingredients and feeding practices in New Zealand's production animal industries. For this reason, this Risk Profile will also consider a wider definition of feed, to include all non-pasture and non-forage-based feeds. However, forage and pasture feeds are considered in scope where they are used as ingredients in compound feed. The focus is particularly on commercially produced feed types.

### **2.2.1 Types of animal feed in New Zealand**

Animal feed refers to a range of naturally occurring ingredients fed to food animals (cattle, sheep, goats, deer, pigs, poultry) for the purpose of sustenance and growth. Feed can be categorised in a variety of ways; for the purposes of this Risk Profile, feed is segregated into the four following categories below. The feed may comprise the components individually, or multiple components from different categories (for example, when formulated into compound feeds).

#### **1. Forages or roughages (not in scope unless used as compound feed ingredient)**

Forages or roughages are plant-based feedstuff materials, and are generally high in fibre and low in energy. Enzymes from rumen microbiota are important for the degradation of high fibre content. Forages or roughages may be:

- high moisture (for example, pasture, fodder crops, silage, haylage and baleage), or
- low moisture (for example, hay and straw).

Pasture grasses, herbs and legumes are the single most important feed for ruminants such as cattle, sheep, deer and goats in New Zealand. There are many types of plant cultivars grown for pasture, depending on the region, growing conditions and the livestock species. In 1999, there were 109 different pasture plant cultivars available in New Zealand, from 23 different species (Charlton and Steward 1999).

Hay is produced from pasture crops that have reached the stage of maximum plant growth and are harvested and dried before the seed develops.<sup>3</sup> The moisture content is typically low (<18%) to prevent microbial spoilage. Similar to hay, straw is produced from residual material following the harvesting of seed from cereal crops.

The most common types of non-pasture forage crops grown in New Zealand are fodder beet, forage brassicas, forage cereals and maize.<sup>4</sup> Root forage crops, such as swedes and turnips are also fed to New Zealand livestock. Many of these crops can be consumed by animals either directly in-ground, or provided as harvested or ensiled products.

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<sup>3</sup> <https://www.britannica.com/topic/feed-agriculture/Roughages>; accessed 21 July 2023

<sup>4</sup> <https://www.cropscience.bayer.co.nz/crops/forage>; accessed 21 July 2023

Silage is fodder converted into succulent feed for livestock through processes of anaerobic bacterial fermentation.<sup>5</sup> It is made from pasture or crops that have been cut, compacted, and stored at a point where the moisture remains relatively high (60-75%). Haylage and baleage are terms for fodder wrapped in plastic to undergo fermentation, where moisture content is still high but may be more variable. Anaerobic fermentation by bacteria naturally present causes the pH to drop through the production of acetic and lactic acids, helping preserve the feed. Incomplete fermentation can lead to foul odours, unpleasant textures, loss of nutrients, and production of bacterial and fungal toxins, with the palatability and digestibility for livestock also affected (Ávila and Carvalho 2020).<sup>6</sup> Depending on the nutritional value of different products, they may be augmented with additives; for example, magnesium is often added back to maize silage. Pathogens that survive acidic environments, like *L. monocytogenes* and *C. perfringens* spores, are of most concern in silage (Ávila and Carvalho 2020).

## 2. Concentrates

Concentrates are prepared from cereals and additional feed components. They are generally low in fibre, and high in energy and/or protein content, fat and digestibility. Examples include cereal grains, vegetable or fruit pulp, nuts, molasses, fats and oils.

## 3. Supplements

Feed supplements can be plant based, for example, legumes, brewery/distillery by-products, palm kernel expeller/extract meal (PKE) and copra; or rendered product of animal origin, for example blood and bone meal, fish, chicken litter or dried milk products.

PKE is a dry, gritty meal by-product of the palm oil industry in South East Asia. It contains reasonable levels of metabolizable energy and protein. The import of PKE into New Zealand increased ten-fold between the mid-2000s and the mid-2010s. Imports have since levelled off.<sup>7</sup> PKE may be included as a component of compounded or blended feeds, but is more commonly fed directly to dairy cows.

Copra cake or copra meal is the product remaining after crushing of coconut to extract oil. Copra use has decreased in New Zealand since 2006, when its direct feeding to dairy cows was prohibited due to concerns over the presence of aflatoxin B1.<sup>8</sup> NZFSA (a predecessor to NZFS) have developed a Code of Practice to control aflatoxin in copra (New Zealand Feed Manufacturers Association and Dairy Companies Association of New Zealand 2008).

Distiller's Dried Grains with Solubles (DDGS) is the dried residue left after fermentation of the starch fraction of maize to produce ethanol. All DDGS used in New Zealand feed is currently produced domestically (Table 1). Internationally, increases in the production of biofuels has resulted in increased availability of DDGS, with about 98% of the DDGS in North America now coming from production of oxygenated fuels.<sup>9</sup> DDGS is commonly used in United States (US) beef feedlots, where its abundance from the bourbon industry was a driver for establishing feedlots. DDGS was first imported into New Zealand in 2008 (Davidson and Pearson 2009).

Rendering of animal products for feed involves the breaking down of animal tissues into the constituent fat and protein elements, and may be employed to ensure that these by-products are safe and suitable for purpose. Animal product sent for rendering may include product

<sup>5</sup> <https://www.merriam-webster.com/dictionary/silage>; accessed 5 July 2022

<sup>6</sup> <http://www.omafra.gov.on.ca/english/crops/field/forages/silage-ferm-prob.htm>; accessed 16 March 2023

<sup>7</sup> <https://www.indexmundi.com/agriculture/?country=nz&commodity=palm-kernel-meal&graph=imports>; accessed 12 April 2023

<sup>8</sup> <https://www.mpi.govt.nz/dmsdocument/33262/direct>; accessed 24 July 2023

<sup>9</sup> <https://biofuelscoproducts.umn.edu/overview-ddgs>; accessed 24 July 2023

deemed as “medium-risk”, that is not fit for human or animal consumption without further processing or treatment. This may include, but are not limited to, farm animals that have died in the field, derived from home-kill or recreational catch, animal material that has come into contact with any other medium risk material, or material derived from animals suspected to be diseased or that are slaughtered for specific disease eradication purposes, which includes *S. Enteritidis*-positive poultry flocks (New Zealand Food Safety Authority 2009, Ministry for Primary Industries 2022a). Rendering in New Zealand is achieved by thermal processing, which is the application of heat, with or without the addition of pressure.<sup>10</sup> Rendered animal products include tallow, fish oil, poultry oil, meat meals, meat and bone meals, dried blood, blood meal, poultry meal, and feather meal (New Zealand Food Safety Authority 2009). Rendered ruminant protein is not permitted for use in feed for ruminants (predominantly, cattle, buffalo, sheep, goats and deer) because bovine spongiform encephalopathy (BSE) was associated with the practice of feeding of ruminant-derived protein to cattle (Wilesmith et al. 1988). The prion protein that causes BSE can remain viable through the rendering process (Pandey et al. 2020). Unless the thermal processing step is insufficient or cross-contamination after processing occurs, rendered product should be free of microbiological hazards. Processed meal products should also be suitably dried to prevent growth of microorganisms and the deterioration of the product (Ministry for Primary Industries 2022a). Chemical hazards are not eliminated by rendering and are outside the scope of this Risk Profile.

#### 4. Additives

Additives refer to ingredients that are added to feed to enhance the nutritional value of base feed, or for enhancing weight gains. Examples of nutritional additives include vitamins, minerals, buffers and flavours.

A number of feed additives are also available that are designed to reduce gastrointestinal colonisation by *Salmonella*, particularly for poultry feed (Gast et al. 2022b). Examples include:

- Probiotics: direct-fed microbes for competitive exclusion to impede *Salmonella* colonisation;
- Prebiotics: compounds that are utilisable by beneficial gut microbiota, and promote their growth;
- Phytochemicals: plant-derived antimicrobials such as essential oils, botanicals, herbs, and oleoresins;
- Organic acids: added to feed to inhibit the growth of fungi and to limit the growth and survival of pathogens such as *Salmonella*. Examples include short-chain fatty acids, propionate, formate and butyrate.
- Bacteriophages: viruses that specifically target bacteria as a host. The high level of specificity of phages (often, specific to only a few serotypes or strains within a serotype) means that they are typically prepared as a phage mixture when intended for therapy. Development of resistance and changing populations of *Salmonella* can limit the efficacy of phage therapy. Bacteriophages are not currently used in New Zealand animal feed.

As discussed in Section 4.2.3, in the past, animal feed had often been supplemented with antibiotic growth promoters at a low, sub-therapeutic dose to improve productivity rather than for treating disease. The use of antibiotic growth-promoters has been banned in EU countries since 1 January 2006,<sup>11</sup> as well as many other countries, and are not approved for growth promotion in New Zealand. Previously, the major antibiotic additive used in broiler poultry feed

<sup>10</sup> <https://mia.co.nz/assets/Uploads/Dunn-Rendering-Systems-in-NZ-2020.pdf>; accessed 7 August 2023

<sup>11</sup> [https://ec.europa.eu/commission/presscorner/detail/en/IP\\_05\\_1687](https://ec.europa.eu/commission/presscorner/detail/en/IP_05_1687); accessed 21 July 2023

in New Zealand was zinc bacitracin, but its prophylactic use will cease this year (2023).<sup>12</sup> Zinc bacitracin was used as a prophylactic for the control of necrotic enteritis caused by a *Clostridia* species for which there is no poultry vaccine. Based on 2012 data from 30 countries, New Zealand was the third lowest user of antimicrobials in animal production (Hillerton et al. 2017).

## 2.2.2 Manufacture of animal feed

The majority of compound animal feed manufactured in New Zealand is processed through feed mills operated by members of the New Zealand Feed Manufacturers Association (NZFMA).<sup>13</sup> NZFMA represents the interests of almost all animal feed manufacturing companies in New Zealand. Information was not found on feed manufacturers that do not belong to NZFMA, or on small operations/farms that manufacture their own feed.

While individual feed formulations will vary in composition, the overall use of raw materials in the production of compound feeds in 2022, as listed in Table 1, was:

- Grains, for example sorghum, wheat, barley, maize, oats and triticale: 63%
- Plant proteins, for example peas, soy meal, copra and PKE: 20%
- Animal proteins, for example milk powders, meat, bone and blood meal, fishmeal: 3%
- Grain by-products, for example wheat bran, broil, pollard, malt culms: 6%
- Oils and tallows: 1%
- Other, for example roughages, molasses, salt, limestone, vitamins, minerals: 7%

For considering RMQ2 regarding the risk of introduction of *Salmonella* into food-producing animals following the detection of *S. Enteritidis* in chicken products and on farms, it is important to note no poultry by-product protein meal was used for feed manufacture in 2021<sup>14</sup> or 2022 (Table 1). Usage in 2020 (14.0 tonnes from domestic production, no imported product) was a 91.2% reduction from that used in 2019 (110 tonnes<sup>15</sup> from domestic production and 50.0 tonnes imported). Poultry fat was still used as a feed material in 2022 (1,054 tonnes, all domestically produced), although the amount used was 72.1% less than in 2021 (3,775 tonnes). Poultry protein is not used in poultry feed (by Poultry Industry agreement) or calf feed in New Zealand, but may be used by home millers of pig feed or in pet food (not covered in this Risk Profile) (Kerry Mulqueen, PIANZ, pers. comm. August 2023). The majority of rendered animal product is exported.<sup>16</sup>

Production of animal feed in New Zealand has been fairly stable during the period 2015 to 2022, with total production of approximately 1.1 million tonnes per annum (New Zealand Feed Manufacturers Association 2023a). However, there has been a 22% increase in the production of animal feed in New Zealand since 2011, when the total production was approximately 0.9 million tonnes. This reflects increases in the production of feed since that time for the poultry, dairy, calf and other ruminant sectors; conversely, there has been a minor decrease in the total for feed production for pigs. Feed was mainly manufactured in the North Island (65%) and produced in a bulk form (87%), rather than bagged.

Manufacture of animal feed is a complex process, which varies depending on the type of feed. A high-level overview of compound feed manufacture is outlined in Figure 2. In general, the

<sup>12</sup> <https://az659834.vo.msecnd.net/eventsairaeuprod/production-nzvaevents-public/64c002bd04e348b5bb328686b9b3e2a8>; accessed 6 June 2023

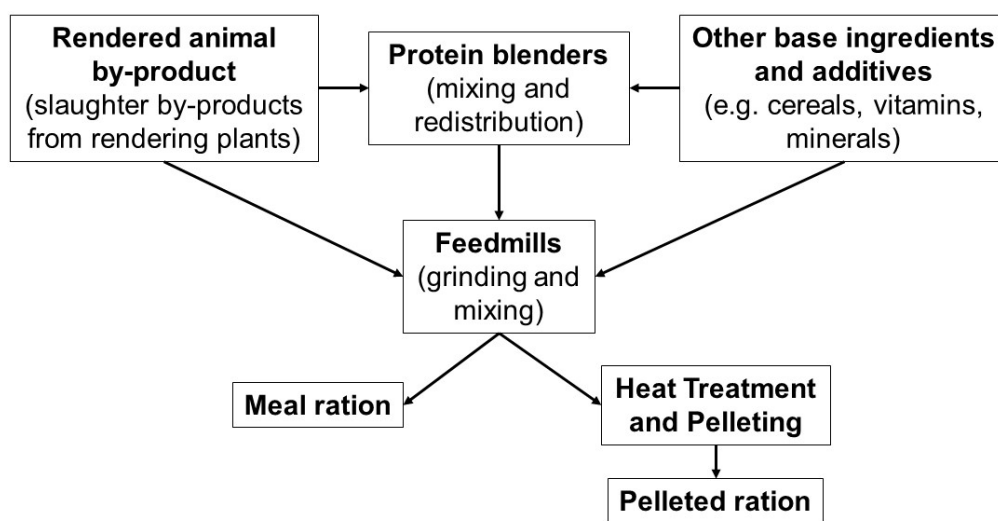
<sup>13</sup> <https://www.nzfma.org.nz/>; accessed 23 March 2023

<sup>14</sup> <https://www.nzfma.org.nz/media/>; accessed 7 August 2023

<sup>15</sup> Note that this figure differs from the 816 tonnes which was an error reported in the 2019 report (Kerry Mulqueen, PIANZ, pers. comm.)

<sup>16</sup> <https://mia.co.nz/assets/Uploads/Dunn-Rendering-Systems-in-NZ-2020.pdf>; accessed 10 August 2023

process involves grinding selected ingredients, typically using hammer or roller mills, to increase the surface area for nutrient digestion and to improve heterogeneity in feed (Ministry for Primary Industries 2021c, Perera et al. 2021). Milled feed is then proportioned and mixed. Mixing may be followed by a pelleting step, which typically involves initial steam conditioning heat treatment of the mash to soften the mixture, gelatinise starch and improve binding, with the added benefit of reducing microbial contaminants. The hot mash is then extruded through a metal die of the desired shape under pressure, followed by cooling. The cool and dry pellets may then pass through a crumbler, depending on the product being manufactured (Perera et al. 2021). Products such as poultry mash do not generally undergo a heat treatment step, although some heating at low temperatures may occur to aid the mixing of ingredients (Kerry Mulqueen, PIANZ, pers. comm., 2 October 2023). Information was not available on the proportion of manufactured feed that does not undergo a heat treatment process.



**Figure 2. Overview of steps in compound animal feed manufacture. Adapted from Crump et al. (2002).**

**Table 1. Sources and types of raw materials used in feed production in New Zealand, 2022 (NZFMA annual feed production statistics<sup>1</sup>).**

Raw Material	Source, tonnes (percent by source)		Total tonnes (percent of total materials)
	Domestic	Imported	
<b>Grains</b>			
Wheat	144,777 (29.3)	349,927 (70.7)	494,703 (44.1)
Barley	78,977 (76.1)	24,754 (23.9)	103,731 (9.2)
Oats	1,949 (100.0)	-	1,949 (0.2)
Maize	41,960 (61.0)	26,841 (39.0)	68,801 (6.1)
Sorghum	-	35,413 (100.0)	35,413 (3.2)
Triticale	2,995 (100)	-	2,995 (0.3)
Other	8 (1.5)	528 (98.5)	536 (<0.1)
<b>Subtotal</b>	<b>270,665<sup>2</sup> (38.2)</b>	<b>437,462 (61.8)</b>	<b>708,128 (63.1)</b>
<b>Grain by-products</b>			
Wheat (bran, pollard, broll)	59,470 (100.0)	-	59,470 (5.3)
Barley (malt culms, brewers grain)	2,786 (100.0)	-	2,786 (0.3)
Other	2,675 (68.2)	1,246 (31.8)	3,921 (0.4)
<b>Subtotal</b>	<b>64,932 (98.1)</b>	<b>1,246 (1.9)</b>	<b>66,177 (5.9)</b>
<b>Animal proteins</b>			
Meat and bone meal (non-poultry)	28,122 (98.3)	492 (1.7)	28,614 (2.6)
Bloodmeal (non-poultry)	2,101 (99.4)	13 (0.6)	2,114 (0.2)
Fishmeal	2,447 (98.4)	40 (1.6)	2,487 (0.2)
Poultry by-product meal	-	-	-
Milk powders	4,905 (95.3)	240 (4.7)	5,145 (0.5)
Other	43 (100.0)	-	43 (<0.1)
<b>Subtotal</b>	<b>37,617 (98.0)</b>	<b>785 (2.0)</b>	<b>38,403 (3.4)</b>
<b>Oils and Tallows</b>			
Vegetable oils	5,267 (97.4)	139 (2.6)	5,406 (0.5)
Poultry fat	1,054 (100.0)	-	1,054 (0.1)
Tallow (non-ruminant feed)	5,667 (100.0)	-	5,667 (0.5)
Tallow (ruminant feed)	60 (100.0)	-	60 (<0.1)
<b>Subtotal</b>	<b>12,048 (98.9)</b>	<b>139 (1.1)</b>	<b>12,186 (1.1)</b>
<b>Plant proteins</b>			
Peas	1,948 (100.0)	-	1,948 (0.2)
Soya meal	-	158,144 (100.0)	158,144 (14.1)
Copra	-	734 (100.0)	734 (0.1)
Palm kernel extract (PKE)	-	23,299 (100.0)	23,299 (2.1)
Other	6,749 (16.8)	33,407 (83.2)	40,156 (3.6)
<b>Subtotal</b>	<b>8,697 (3.9)</b>	<b>215,584 (96.1)</b>	<b>224,281 (20.0)</b>
<b>Roughages</b>			
Lucerne/alfalfa hay	148 (55.4)	119 (44.6)	268 (<0.1)
Other	1,569 (99.4)	9 (0.6)	1,578 (0.1)
<b>Subtotal</b>	<b>1,717 (93.0)</b>	<b>129 (7.0)</b>	<b>1,846 (0.2)</b>
<b>Others</b>			
Limestone	21,146 (96.3)	822 (3.7)	21,968 (2.0)
Other	33,232 (66.4)	16,799 (33.6)	50,030 (4.5)
<b>Subtotal</b>	<b>54,377 (75.5)</b>	<b>17,621 (24.5)</b>	<b>71,998 (6.4)</b>
<b>Grand total</b>	<b>450,054 (40.1)</b>	<b>672,964 (59.9)</b>	<b>1,123,018</b>

<sup>1</sup> Data source: <https://www.nzfma.org.nz/wp-content/uploads/2023/03/Annual-Feed-Production-Statistics-YE-2022-Copy-1.pdf>; accessed 28 September 2023

<sup>2</sup> The subtotals for each category were based on the data presented by NZFMA. In some cases, the subtotals differed slightly from actual totals of the presented data, which we presume was due to rounding error.

### 2.2.3 International trade of raw ingredients

Approximately 60% of the raw materials used in the production of compound animal feed in New Zealand are imported, with imported materials mainly from the grain and plant protein categories.<sup>17</sup> The relative amounts of imported materials used in feed production are listed in Table 1. Some products are also consumed directly, so overall volumes imported for feed are higher than listed in Table 1.

PKE is imported for direct use as a feed, in addition to its incorporation into compound feed. The import of PKE for use as dairy cattle feed increased ten-fold between the mid-2000s and the mid-2010s. Imports have since levelled off.<sup>18</sup> In total, 1.97 million tonnes of PKE were imported into New Zealand in 2022; 23,299 tonnes of which were used as raw material in feed production. For the period 2015 to 2022, annual imports were in the range 1.50 to 2.24 million tonnes. This is an increase from the 1.1 million tonnes imported in 2008, as reported in the 2011 Risk Profile (Cressey et al. 2011).

The import of grains for feed production has also significantly increased since the 2011 Risk Profile (Cressey et al. 2011), with 172,833 tonnes imported in 2008 increasing to 672,964 tonnes in 2022.<sup>17</sup>

Soya meal, the by-product following the extraction of oil from soybeans, is the second most imported feed raw material for manufactured feed, and can also be direct-fed. The 158,144 tonnes used imported in 2022 for feed production (Table 1) is an increase from the 108,225 tonnes from 2008 reported in the 2011 Risk Profile. Volumes have been in the range of 133,453 to 169,777 tonnes since 2018.

Importation of cottonseed for use as feed reached a peak in 2012 (26,626 tonnes) but has since completely ceased.<sup>17</sup>

### 2.2.4 Livestock farming overview and feed requirements by sector in New Zealand

Ruminant species in New Zealand are generally raised on pasture systems, with forage crops and supplementary feeds used during winter or drought conditions. Pigs and poultry are monogastric non-grazing species that require a year-round supply of harvested and/or processed feed that is more highly digestible than pasture-based feed year-round. This section considers the relative size and specific feed requirements of each livestock sector. Table 2 lists the volumes of the predominant dry matter supplementary feeds for 2017-2019 for dairy cattle and for 2014-2015 for other cattle and sheep. Table 3 summarises the quantities of compound feed per sector produced by NZFMA members in 2022. Table 4 provides an overview of compound feed type by each sector, as was included in the 2011 Risk Profile (Cressey et al. 2011).

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<sup>17</sup> <https://www.nzfma.org.nz/wp-content/uploads/2023/03/Annual-Feed-Production-Statistics-YE-2022-Copy-1.pdf>; accessed 2 June 2023

<sup>18</sup> <https://www.indexmundi.com/agriculture/?country=nz&commodity=palm-kernel-meal&graph=imports>; accessed 12 April 2023

**Table 2. Calculated weight (tonnage dry matter) of various supplementary feed by type eaten by livestock in New Zealand, for 2017-2018 (dairy cattle) or 2014-2015 season (other cattle and sheep) (DairyNZ, 2019; Sise et al., 2018).**

Feed type	Dairy cattle (tonnes)	Beef cattle (kg)	Other cattle (kg)	Sheep (kg)
Baleage	-	6,752	11,255	14,577
Barley	65,087	-	-	-
Barley silage	-	-	-	3,068
Cereal whole crop silage	37,800	-	-	-
Cottonseed	6,556	-	-	-
Fodder beet	752,400	-	-	-
Kale	208,000	10,230	26,300	-
Maize grain	51,007	-	-	-
Maize silage	936,700	-	-	-
Oats	2,791	-	-	-
Palm kernel expeller/extract (PKE)	1,561,225	-	-	-
Rape	56,000	-	-	-
Sheep nuts	-	-	-	4,251
Soyabean meal	24,087	-	-	-
Swedes	236,640	23,394	22,731	43,120
Tapioca	4,981	-	-	-
Turnips	240,000	-	-	-
Turnips (leafy)	-	-	-	28,363
Wheat	14,145	-	-	-
Other supplements <sup>1</sup>	230,487	-	-	-
<b>Total</b>	<b>4,427,908</b>	<b>40,376</b>	<b>60,286</b>	<b>93,379</b>

<sup>1</sup>Includes molasses, PROLIQ®, imported grains, fishmeal, horticultural by-products such as vegetables and fruit.

**Table 3. Compound feed produced in New Zealand, 2022.**

Species/type	Production (tonnes)		
	North Island	South Island	Total
Poultry-broiler	384,122	87,138	471,260
Poultry-broiler, breeder flocks	40,621	8,521	49,142
Poultry-layer (including rearing and breeder flocks)	121,521	47,899	169,420
Pig-grower	28,942	109,797	138,739
Pig-breeder	7,373	16,243	23,616
Calf-milk replacers	3,909	-	3,909
Calf-meals, pellets, crumbles	42,900	30,740	73,640
Calf-textured feeds	5,870	1,844	7,714
Cattle-dairy	76,936	58,125	135,061
Cattle-beef, sheep, deer, goats	11,913	12,694	24,607

Source: <https://www.nzfma.org.nz/wp-content/uploads/2023/03/Annual-Feed-Production-Statistics-YE-2022-Copy-1.pdf>; accessed 24 May 2023

**Table 4. Compound feed types used in food animal product in New Zealand.**

Sector	Compound feed type	Use characteristics
Dairy cows - calves	Milk replacer Lower protein starter ration High protein starter ration	Birth to 6-12 weeks 4-16 weeks Birth to 10-12 weeks
Dairy cows – production	Springer (pre-calving) Early lactation ration Mid lactation ration Late lactation ration	2-3 weeks prior to calving Up to 120 days into lactation 100-200 days into lactation 200-300 days into lactation
Beef cattle - production	Not commonly used, but some supplementary feeding of pelleted ration	40 days before slaughter
Sheep and goats	Rarely used	
Deer	Velvet ration	From beginning of August
Pigs	Creep Weaner 1 Weaner 2 Grower Finisher Dry sow Lactating sow Gilt replacer Boar	Birth to 3-5 weeks Weaning to 2 weeks post weaning From 2-12 weeks post weaning 12-16 weeks 16 weeks to market
Ostriches and Emus	Starter Grower Finisher In-lay Out-of-lay	Birth to 4-6 weeks 4 weeks to 1-2 months Top-up ration
Broiler poultry – breeder stock	Starter Rearer Grower Prelay Early Layer Late Layer	Hatching to 4 weeks 4-8 weeks Up to 16 weeks Up to about 21 weeks 21-40 weeks
Broiler poultry – production	Starter Grower Finisher Withdrawal	Hatching to 7 days 7-20 days Up to 35 or 42 days Final 5-7 days pre-slaughter
Layer poultry	Starter Grower Pre-lay Early Lay Late Lay	Hatching to 4 weeks 4-16 weeks 16-40 weeks 40-60 weeks Up to 60 weeks or longer

## Dairy cattle

The New Zealand dairy industry has expanded considerably over the last 30 years (DairyNZ 2019). The number of cows milked increased from 2.40 million in 1990-1991, to 5.02 million in 2014-2015; while there has been a slight decline in more recent years to 4.84 million in 2021-2022.<sup>19</sup> There has been an increase in land area used for dairy production, from 1,023,545 effective hectares in 1990-1991 to 1,701,380 hectares in 2021-2022. The industry has also become more intensive with higher stocking rates, increasing from an average of 2.35 cows per hectare in 1990-1991 to 2.85 in 2021-2022. Milk production per cow has also increased from an average of 259 kg of milksolids per cow in 1992-1993 to 386 kg in 2021-2022.

Improved milk production and increased days in milk have been supported through increasing feed levels and quality. Use of PKE, forage crops such as fodder beet and brassicas, and root crops such as turnips and swedes, have increased. DairyNZ recommends that supplementary feeds and crops only be used when available pasture is less than herd demand, and when benefits outweigh the costs.<sup>20</sup> The most consumed non-pasture supplemental feeds for 2017-2018 for dairy cattle in New Zealand (as calculated by area sown, harvest volume, and import quantities) were PKE, maize silage, and fodder beet (Table 2) (DairyNZ 2019). Each are described below:

- PKE has a soapy flavour and is not very palatable to cows until they acquire a taste for it. It contains reasonable levels of metabolizable energy and protein. When in use, PKE may comprise up to 30% of the cow diet. In 2018, Fonterra introduced a Fat Evaluation Index grading system to measure the suitability of milk fat composition, which can be affected, among other things, by the proportion of a cow's diet that is comprised of PKE.<sup>21</sup>
- Maize silage is commonly used as a supplement to pasture in situations where cows would be underfed.<sup>22</sup> It has similar levels of metabolizable energy as PKE. When in use, it ideally comprises only up to 30% of the diet to avoid amino acid and protein deficiency, but can be up to 40% of the diet for milking cows or 50% for dry cows, depending on the protein content of the pasture.
- Fodder beet can comprise up to 40% of the diet for milking cows or 70% for dry cows. Because of its high sugar content, its use needs to be carefully managed to prevent animal health risks such as rumen acidosis.

DairyNZ classifies five production systems with respect to pastoral farming in New Zealand, based on the percentage of imported feed that is used:<sup>23</sup>

- System 1 - All grass self-contained, 100% home-grown feed with all adult stock on the dairy platform. No feed is imported. No supplement is fed to the herd except supplement harvested off the effective milking area and dry cows are not grazed off the effective milking area.
- System 2 - 90-99% of total feed is home-grown feed. 1-10% of feed is imported either as supplement or grazing off for wintering dry cows.

<sup>19</sup> <https://www.dairynz.co.nz/publications/dairy-industry/new-zealand-dairy-statistics-2021-22/>; accessed 19 July 2023

<sup>20</sup> [https://www.dairynz.co.nz/media/5795018/facts\\_and\\_figures\\_dnz30-001\\_updated\\_dec\\_2021\\_v6.pdf](https://www.dairynz.co.nz/media/5795018/facts_and_figures_dnz30-001_updated_dec_2021_v6.pdf); accessed 28 August 2023

<sup>21</sup> <https://www.fonterra.com/nz/en/our-stories/media/fat-evaluation-index-grading-system-to-begin-september-2018.html>; accessed 12 April 2023

<sup>22</sup> <https://www.dairynz.co.nz/feed/supplements/maize-silage/>; accessed 19 July 2023

<sup>23</sup> <https://www.dairynz.co.nz/business/the-5-production-systems/>; accessed 24 July 2023

- System 3 - 80-89% of total feed is home-grown feed. 11-20% of total feed is imported to extend lactation (typically autumn feed) and for wintering dry cows.
- System 4 - 70-79% of total feed is home-grown feed. Approx 21-30% of feed imported and used at both ends of lactation and for wintering dry cows.
- System 5 - 50-69% of total feed is home-grown feed: More than 31% of feed imported and used throughout lactation. Feed imported could be greater than 50%.

## Beef cattle and sheep

As of June 2022, the number of sheep farmed in New Zealand was 25.3 million, which is a reduction from the 31.1 million sheep farmed in 2011.<sup>24</sup> Depending on the breed, these may be reared for the wool and/or meat industry, and a growing number of operations raise dairy sheep. Beef cattle numbers have been relatively stable, with 3.8 million farmed in 2011 and 3.9 million in 2022.

The most consumed non-pasture supplements for beef cattle and sheep over this period were swedes, baleage, and kale (Table 2) (Sise et al. 2018). The amount and type of feed supplementation depends on the amount and quality of pasture feed, and the nutrient demands of the grazing animal; for example, pregnant ewes have a different nutrient requirement than lactating or dry ewes.<sup>25</sup> Smaller and lighter animals require feed with a higher nutritive value due to limited rumen capacity; for example, high quality hay is a better supplement for protein and energy than very wet silage. Grains with high protein and high metabolizable energy should be used when paddock feed is not limiting. Wet silage and low quality hay are better fed to larger animals, such as crossbred ewes or cattle. Other considerations for grain (in addition to cost and availability) depend on the nutrients that require boosting, and the time taken for rumen bacteria to adapt to prevent acidosis; oats and lupins are safer options than wheat in this regard.

The main compound feed that may be fed to sheep is sheep nuts (Table 2). Typical ingredients include grains (wheat, barley, maize, triticale), grain by-products, oilseed meals and by-products, grass seed meal, legumes, molasses, sodium bentonite, zeolite, vegetable oil, mould inhibitor, minerals and vitamins (for example, cobalt, iodine, manganese, selenium, zinc, calcium, sodium and vitamins A, D and E).<sup>26</sup>

Minerals may be supplemented into other types of feed, but depending on the mineral, applying the mineral via drenching or injection of the animal is a more cost-effective option.

## Deer

Deer are produced commercially in New Zealand for both meat and velvet production. There were 794,000 farmed deer in New Zealand in 2022, which was a decrease from the 1,089,000 recorded in 2011.<sup>24</sup> The amount of venison produced has reduced by approximately one half since 2011; with 22,920 tonnes carcass weight equivalent produced in 2011 down to 10,725 in 2021.<sup>27</sup> Deer are also farmed for velvet, the production of which has increased from 498 tonnes in 2011-2012 to 956 tonnes in 2020-2021. Much of New Zealand-produced deer product is exported; the largest amount of venison is exported to the US, while China is the largest importer of velvet and co-products (for example, offal, pizzles and tails).

<sup>24</sup> <https://www.stats.govt.nz/information-releases/agricultural-production-statistics-year-to-june-2022-final/>; accessed 20 July 2023

<sup>25</sup> <https://beeflambnz.com/knowledge-hub/PDF/feed-quality.pdf>; accessed 20 July 2023

<sup>26</sup> <https://nrm.co.nz/spec-sheets/nrm-sheep-nuts/>; accessed 20 July 2023

<sup>27</sup> <https://www.deernz.org/home/deer-industry-new-zealand/statistics/>; accessed 20 July 2023

Farmed deer in New Zealand are predominantly pasture-fed via rotational grazing, with pastures comprising a mix of grasses, clovers and herbs.<sup>28</sup> During winter and in droughts, when grass growth slows, deer may be fed on forage crops, for example turnips or kale, and conserved pasture, such as hay and silage. They may also be given small quantities of grain, nuts and other plant-based supplements to balance their diet while they are on crops or conserved feeds.

## Goats

Goats are raised commercially in New Zealand for meat, milk or mohair production, and are also used as weed control. There were 88,400 goats farmed in 2022, which was a slight increase from the 86,000 farmed in 2011.<sup>29</sup> One source of data listed 66,100 dairy goats from 92 farms operating in New Zealand and 9,320 Angora goats farmed on 110 properties (Scholtens et al. 2017).<sup>30</sup> The majority of goats processed for meat are feral, which included 90% of the goats slaughtered for meat over the 2014-2016 period. Of the 123,575 killed in 2016, the majority (77,376) were exported.

Goats eat a wide variety of on-farm forages such as grasses, clover, lucerne or pasture plants, and can eat some plant types that are unpalatable to cows and sheep. They require good pasture year-round, and additional supplements such as hay, silage or concentrate during winter, especially for milk-producing goats.<sup>31,32</sup>

## Pigs

There were approximately 672,500 piglets weaned from approximately 80 commercial farms in New Zealand in 2022, which is a 9% increase from 2017 when there were 614,800.<sup>24,33</sup>

Pigs differ from ruminant livestock socially and behaviourally, and have a greater need for shelter.<sup>34</sup> Approximately 55% of the commercial herd is raised indoors, 42% in outdoor free-farmed systems (sows and boars live outdoors and are provided with shelter; sows give birth in individual huts with outdoor access, and after weaning, pigs are raised in barns on bedding), and 5% are fully free range (similar to free-farmed but while newly weaned pigs may be kept for a short period in a fenced outdoor pen with shelter, they are reared fully outdoors during the grower-finisher period).

In contrast to sheep, cattle, goats and deer, pigs are not primarily grazing animals. Like poultry, pigs are largely reliant on harvested and/or processed feed for health and nutrition year-round. They require a balanced formulated mix of grains and cereals for energy, sources of protein such as dairy by-products, and soya bean meal, along with vitamins and minerals. New Zealand pig feed has not been supplemented by porcine somatotropin growth hormone since 2002.

Food by-products of commercial food production for humans may also be used for pig feed (New Zealand Feed Manufacturers Association 2023b). Examples include dairy products, bread, fruit, vegetables and manufactured items that are excess to requirements for human consumption and/or do not meet particular specifications. Acceptable by-products must be:

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<sup>28</sup> <https://www.deernz.org/home/the-deer-difference/free-range-deer-farming/>; accessed 20 July 2023

<sup>29</sup> <https://figure.nz/chart/3s8vdsO6MN4M08lo-aOhOWM32hlweIR2u>; accessed 20 July 2023

<sup>30</sup> <https://www.agrifarming.in/goat-farming-in-new-zealand-breeds-how-to-start-tips-and-ideas>; accessed 20 July 2023

<sup>31</sup> <https://www.mohairproducers.co.nz/get-started/mohair-nutrition/>; accessed 20 July 2023

<sup>32</sup> <https://www.dgc.co.nz/made-responsibly/pasture-fed/>; accessed 20 July 2023

<sup>33</sup> <https://www.nzpork.co.nz/about-us#annual-reports>; accessed 20 July 2023

<sup>34</sup> <https://www.nzpork.co.nz/farmers/pork-farming-styles-in-new-zealand>; accessed 20 July 2023

- non-toxic to pigs, and be free of contamination, deterioration, putrefaction or fermentation that would render the material unsuitable for the purpose intended,
- contain no porcine material,
- have an assurance that it contains no 'untreated' meat, or if it contains meat, it must have been treated by heating to at least 100°C for one hour,
- be free of extraneous organic or inorganic matter at source.

## Poultry

Poultry is a descriptive term for the domesticated breeds of birds including chickens, turkeys, ducks, geese, guinea fowl and quail that are farmed for their meat and eggs.<sup>35</sup> The term "broiler" is used for a chicken of the species *Gallus gallus domesticus* that is bred specifically for meat production (compared with the term "layer" which has been bred specifically for egg production), and is farmed from when it is a day-old chick until it is supplied for primary processing. In New Zealand, chickens are by far the largest group of farmed birds.

Data from the Poultry Industry Association of New Zealand (PIANZ) indicates that there were 218,800 tonnes of chicken meat produced in 2022 from approximately 119.5 million broiler chickens.<sup>36</sup> This has increased from approximately 150,000 tonnes of poultry meat produced from 85 million birds in 2010.

In 2022, there were approximately 1.2 billion chicken eggs produced from a per-month average of 3.63 million layer hens. This is an increase in numbers from 2011, when the national flock of layer hens was estimated at 3.31 million birds, producing approximately 1 billion eggs. Production was higher again in intervening years, with as high as approximately 4.2 million birds in lay in April 2020. A new *Code of Welfare* requiring phased prohibition on the use of conventional cages by the end of 2022 (Ministry for Primary Industries 2018), together with a commitment by some supermarkets to only sell cage-free eggs by the end of 2025,<sup>37</sup> impacted egg production.

In addition, data from PIANZ indicate that 900,000 ducks (*Anas pekin* or *Cairina moschata*) and 250,000 turkeys (*Meleagris gallopavo*) are produced per year for meat production. Duck is increasing in popularity in New Zealand, and are farmed in barns to avoid contact with other waterfowl which are carriers of disease.<sup>38</sup> As of October 2016, there were six duck producers listed in the PIANZ-Egg Producers Federation database (Greening et al. 2020). There are three main turkey producers, all located in the Canterbury region.<sup>39</sup> There are also a small number of enterprises that farm quail (two farms) or ducks (one farm) for commercial egg production.

The larger poultry companies are vertically integrated. This means that each company retains ownership of all chickens and manages all aspects of poultry production within their separate companies, which also includes feed production.

Whereas feed for ruminant livestock tends to be seasonal, poultry are largely (if not solely, for those cage- or barn-raised) reliant on harvested and/or processed feed for health and nutrition

<sup>35</sup> <https://www.pianz.org.nz/>; accessed 20 July 2023

<sup>36</sup> <https://www.pianz.org.nz/wp-content/uploads/2020/06/Poultry-Production-Mar-2023.pdf>; accessed 20 July 2023

<sup>37</sup> <https://www.countdown.co.nz/info/community-and-environment/environmental-sustainability/responsible-and-sustainable-sourcing/path-to-cage-free>; accessed 20 July 2023

<sup>38</sup> <https://www.pianz.org.nz/nz-duck/>; accessed 20 July 2023

<sup>39</sup> <https://www.pianz.org.nz/nz-turkey/>; accessed 20 July 2023

year-round. Their feed is manufactured mostly from mixes of grains and cereals such as wheat, corn, sorghum and barley.

### Other sectors

Other species are commercially farmed at low volumes in New Zealand for food production. For example, there are a limited number of emus and ostriches farmed in New Zealand for meat, oil, hide and/or egg production; as of 2017, these numbered 2,330 birds reported.<sup>40</sup> Updated feed data were not found for emus and ostriches, and compound feed usage provided in Table 4 is as was reported in the 2011 Risk Profile (Cressey et al. 2011).

## 2.3 SALMONELLA CONTAMINATION OF ANIMAL FEED AND FEED COMPONENTS

### Key findings

- *Salmonella* contamination of animal feed can occur from contaminated source materials.
- Pelletised feed undergoes a heat treatment step that should eliminate or reduce *Salmonella* numbers.
- *Salmonella* contamination of finished pelletised feed can occur if there is incomplete bacterial inactivation during pelleting, from feed material building up in the equipment or from contaminated dust or raw meal material following the pelleting step.
- Feed contamination can also occur during feed transport, or during storage or while feed is in use at the farm.

### 2.3.1 *Salmonella* contamination of animal feed and feed components

It is considered that the habitat of *Salmonella* is limited to the digestive tract of animals and humans and that its presence in other environments is due to faecal contamination (Jay et al. 2003). Two routes of contamination of animal feed are recognised; contamination of source materials and contamination or recontamination in the feed mill or during transport (Maciorowski et al. 2004). While these contamination routes are relevant for all feed types, pelletised feed undergoes a heat treatment step with the potential to decontaminate or reduce microbial contamination in the feed. The 2011 Risk Profile reported that industry investigations carried out in New Zealand identified three potential mechanisms for *Salmonella* contamination of finished pelletised feed:

- Incomplete inactivation of *Salmonella* by heat during the pelleting process;
- Incidental contamination arising from cross contamination with dust from raw material; and
- Continuous recontamination from deposits of moist contaminated meal within the process, after the pelleting step.

However, it is not possible to say which route of contamination is most important for *Salmonella* being present in the final feed.

### Routes of source material contamination

Feed source material of animal origin may be contaminated with *Salmonella* arising from the animal itself if colonised by this species, or from contamination or recontamination during processing (for example, rendering).

<sup>40</sup> <https://figure.nz/chart/L7Wzd4SZBjYyXTUf-oeNwq8eUDqEbrSH4>; accessed 24 July 2023

Feed source material of plant origin has the potential to become contaminated through direct deposition of *Salmonella*-containing animal faeces or through deposition from irrigation water, irrigated effluent liquids or slurries, effluent sludge, poultry manure, or soil or dust previously contaminated with animal faecal material. New Zealand regulatory requirements for effluent treatment and thresholds of applications to land differ by animal effluent type, region and by nitrogen content of the effluent. For example, in the Waikato region dairy effluent can be applied up to 150 kg nitrogen/hectare/year which equates to approximately 3,300 to 7,600 kg dry matter depending on the effluent type (Norris et al. 2019). Collected dairy effluent is commonly treated in activated sludge effluent ponds before application to pasture; application to forage and arable crops (for example, maize, fodder beet, brassicas and cereals) is less common. Poultry manure undergoes a stand-down of 14-21 days before land application to reduce pathogen loads, and some undergoes more extensive composting (Poultry Association of New Zealand and Egg Producers Federation of New Zealand 2012). Treated human effluent may also be applied to land. Depending on the efficacy of treatment for each effluent type, *Salmonella* might still be present at the time of land application.

Soils can act as a long-term reservoir of *Salmonella*. Examples from individual studies have shown *Salmonella* persist in soil for at least 21 days when contaminated with pig manure, 180 days when contaminated with cattle manure, and up to one year from poultry manure (Nyberg et al. 2014, Pornsukarom and Thakur 2016, Hruby et al. 2018). Note that the survival time differences between studies were at least partly because sampling was not conducted at later time periods. Survival in the soil may be affected by factors such as the physical and chemical characteristics of the manure and soil, weather and atmospheric conditions, biological interactions, agricultural and livestock management practices and *Salmonella* strain variation (Ongeng et al. 2015, Jechalke et al. 2019). There is also limited evidence that *Salmonella* might survive in soils in a viable but non-culturable (VBNC) state (Turpin et al. 1993, Fornfeldt et al. 2018), although the significance of this state is not yet understood.

A growing number of studies have reported that *Salmonella* may be internalised into plant tissues in some circumstances (Heaton and Jones 2008, Ongeng et al. 2011, Standing et al. 2013, Murphy et al. 2016, Jechalke et al. 2019). Plant colonisation may be affected by soil type, *Salmonella* strain and plant type (Jechalke et al. 2019). The degree to which this occurs under real-world conditions and for crops commonly used as components of animal feed is not known.

Cereal crop-producing farms often also raise livestock, which can increase the risk of cross-contamination from animals to feed materials. There are a wide range of animals that may potentially come in contact with feed source material on the farm, during harvest, or during storage and transportation. *Salmonella* has been isolated from a number of animals common in the farm environment, including rodents, wild birds, insects and larger mammals (for example, cats, dogs, raccoons, opossums and foxes) (Meerburg and Kijlstra 2007, Weigel et al. 2007, Umali et al. 2012, Davies and Wales 2013, Chousalkar et al. 2016, Denagamage et al. 2016, Tessier et al. 2016, De Lucia et al. 2018, McWhorter and Chousalkar 2020, Hamilton et al. 2021). In addition, during investigations of the recent outbreak of *S. Enteritidis* associated with poultry in New Zealand (Section 4.2.6), the outbreak strain was isolated from rodents and a hedgehog from affected poultry farms (Kingsbury 2023a).

The prevalence of *Salmonella* contamination differs by the source material. As shown in Table 14 (Appendix A.3), *Salmonella* prevalence is often higher in animal-based materials relative to plant-based feed ingredients (Reiter et al. 2012, Ge et al. 2013, Molina et al. 2015, Hsieh et al. 2016, Parker et al. 2019). Prevalence is also often higher in plant-based materials with

a high oil content such as canola and sunflower meal, which might reflect longer survival by *Salmonella* on these materials (Parker et al. 2019).

### **Contamination at rendering plants and feed mills**

*Salmonella* have been isolated frequently from rendering plant environments, as well as from rendered product (Table 14; Appendix A.3). One study of two US rendering plants reported 79 positive samples of the 108 tested (73%) (Gong and Jiang 2017). The raw materials receiving area was the primary source of *Salmonella*. Surfaces surrounding grinding and finished meal loading-out areas harboured *Salmonella* in biofilms that could recontaminate the finished, rendered meal. Consistent with this, the study found the same serotypes in the receiving area and in finished product. Another study reported that the majority of *Salmonella*-contaminated rendered product likely occurred from recontamination post-processing based on very low contamination rates from samples right after the press compared with much higher prevalence on product being loaded out (Jiang 2016).

As reported in the 2011 Risk Profile (Cressey et al. 2011), inspection of a New Zealand feed mill by the Meat Industry Research Institute of New Zealand (MIRINZ) identified three circumstances likely to contribute to ongoing *Salmonella* contamination:

- Accumulation of moist feed in the conditioner (the main heat treatment point in the process) and in the conditioner feed system during shutdown;
- Failure to divert and reprocess product that had not received full heat treatment; and
- Marginal heat treatment of feed during processing.

At one feed mill, *Salmonella* was isolated from moist feed meal samples from the conditioner, the feed to the conditioner and product from the floor by the packing bin (post-conditioner) (P. D. Lowry, 1989, MIRINZ Confidential Report).

*Salmonella* are frequently isolated from feed mill environments (Table 15, Appendix A.3). Davies and Wray (1997) found widespread contamination of mill environments based on analysis of dust and aggregated fatty material. Mill locations most commonly contaminated with *Salmonella* were intake pits and augers for raw ingredient receipt, the cooling system for pellets or mash, grinders and finished product bins. The mills with the highest overall prevalence of contamination were those where the inside of the cooling system had become colonised by *Salmonella*. Cooling systems are susceptible to *Salmonella* contamination due to the presence of moisture, warmth, high airflow and difficult access for cleaning (Gosling et al. 2022). Waste-handling locations in feed mills have also been found to be significantly more likely to be contaminated with *Salmonella*, while finished product areas had significantly lower prevalence (Gosling et al. 2022).

It has been suggested that *Salmonella* may establish persistent clonal populations within the feed mill environment, resulting in intermittent contamination of feed materials. In a Serbian study, pulsed field gel electrophoresis (PFGE) analysis was carried out on isolates of three *Salmonella* serotypes (*S. Tennessee*, *S. Montevideo* and *S. Infantis*), which had each been repeatedly identified in animal feed samples from three feed mills over a two-year period (Prunic et al. 2016). Isolates of *S. Montevideo* and *S. Infantis* were identical by restriction fragment PFGE. Greater genetic diversity was reported in *S. Tennessee* strains. All strains were shown to be capable of forming biofilms. The authors of this study concluded that the serotypes were likely to be persistent in the respective feed mills.

An isolate of *S. Senftenberg*, known to be heat and desiccation-tolerant, was shown to have persisted in a Swedish feed mill through 1995 and 1996 (Löfström et al. 2006). This serotype

can be particularly problematic due to these resistances and has since been shown to have persisted on a poultry farm for more than two years, despite cleaning, disinfection, desiccation and depopulation (Broennum Pedersen et al. 2008). In Great Britain/UK, *S. Kedougou* has been the most common serotype isolated from feed mills in recent years (2019 to 2021) (Table 15, Appendix A.3) (Animal and Plant Health Agency 2022, Gosling et al. 2022). This serotype is also highly heat and desiccation-tolerant (Pye et al. 2023).

A study investigated the source of *S. Agona* that is a common contaminant in Australian feed mills and product (Parker et al. 2023). Using genomic comparisons of isolates, they determined that *S. Agona* arising from canola meal and meat meal raw ingredients contaminated the finished feed.

Rodent and wild bird faeces collected in and around feed mills have also been demonstrated to contain *Salmonella* (Davies and Wray 1997, Davies and Wales 2010, Davies and Wales 2013). The same *Salmonella* serotype and phage type has been isolated from wild birds and cereal feed mill samples from the same premises (Davies and Wales 2013). While no information on *Salmonella* carriage by wild animals around New Zealand feed mills has been located, *Salmonella* have been isolated from rodents, hedgehogs and wild birds in New Zealand (Robinson and Daniel 1968, Alley et al. 2002, Bloomfield et al. 2017, Fu et al. 2022, Kingsbury 2023a).

### **Contamination during transport and on-farm**

There is potential for feed to become contaminated with *Salmonella* during all means of transportation to the mill and from the mill to the farm (whether by ship, road vehicle, rail, container or other transport system) (European Food Safety Authority 2008). The risk is increased by poor hygiene practices, mainly poor cleaning and disinfection of containers, wheels, equipment for collection, and silos, and also by the presence of vermin and wild birds. As discussed in Section 5.1.2, New Zealand Import Health Standards have requirements in place for storage prior to and during shipping to prevent contamination from vermin and birds (Ministry for Primary Industries 2022c).

Contamination of feed following receipt on-farm can also occur during storage, distribution to the animals, and during use by the animals (such as in feeding troughs). The main sources of contamination by *Salmonella* during storage and distribution at the farm are again vermin and wild birds, pets and other animal species on the farm (European Food Safety Authority 2008, Carlson et al. 2011, Şahin et al. 2022). Cross-contamination can also occur from the livestock themselves; in a study that tested feed on New Zealand poultry farms, the only feed sample that tested positive arose from the layer shed and was indistinguishable from other isolates from elsewhere in the layer shed (Kingsbury et al. 2019). Cross contamination between previous batches of contaminated feed or other products stored at the same place may also occur.

Procedures to decrease the risk of contamination by *Salmonella* on-farm include controlling the moisture of the feed during its storage, enclosing the feed storage site (for example, silo) and feed delivery system to prevent contamination by birds and vermin, and adherence to good biosecurity on-farm. Sectors such as the New Zealand poultry industry have controls in place for feed management on-farm relevant to controlling *Salmonella* contamination (Ministry for Primary Industries 2022a, 2023c).

## 2.4 BEHAVIOUR OF *SALMONELLA* IN FEED AND FEED COMPONENTS

### Key findings

- *Salmonella* will not grow in dry animal feed, but can survive and persist for extended periods of time. Survival times are influenced by the initial concentration of *Salmonella* contamination, serotype present, feed type, and storage conditions. In general, cooler temperatures and a lower  $a_w$  promote *Salmonella* survival.
- *Salmonella* will also not grow in the feed mill environment unless moisture levels are elevated; this has been reported to occur in the pellet cooler system. Biofilm formation that occurs under favourable growth conditions can facilitate *Salmonella* persistence and protect against environmental stresses such as disinfection.
- Heat treatment (70-90°C) is the most effective method used during feed manufacture to inactivate pathogens including *Salmonella*. For pelleted feed, heat is applied by steam and/or dry heat.
- Thermal tolerance of *Salmonella* in animal feed is influenced by the particle size and composition of the feed; for example, the fat content, moisture levels and acidity, as well as the serotype present.
- Feeds may also be treated with chemicals such as organic acids and formaldehyde. These were not as effective as heat for reducing *Salmonella* numbers, but may provide some residual protection against post-production contamination of feed.
- Probiotics, prebiotics and bacteriophages may be added to feed for the purpose of reducing *Salmonella* intestinal colonisation once consumed by livestock or poultry, rather than for controlling any *Salmonella* present in the feed.

### 2.4.1 Growth

*Salmonella* requires proteins, carbohydrates and fats in order to grow and multiply. The composition of the essential nutrients present in feed and feed environments will influence the ability of *Salmonella* to grow. *Salmonella* growth will not occur at an  $a_w$  of  $\leq 0.94$  (Appendix A.1). The feed mill environment, including incoming raw materials, is essentially dry, allowing minimal scope for bacterial growth. The exception to this is the conditioner in which a significant amount of moisture in the form of steam is introduced into the feed. However, the introduction of steam during this process should inactivate any vegetative bacteria such as *Salmonella* if the temperature and time reach inactivation levels.

No reports of growth of *Salmonella* in dry animal feed were identified, although it has been postulated that growth could occur if the feed were allowed to become wet (Jones 2002, 2011). The addition of 40% water to meat and bone meal was sufficient to allow growth of *Salmonella* (Smyser and Snoeyenbos 1979). A high moisture content in feed is likely to result in a range of technological and quality issues. Meal moisture contents of 17% are sufficient to cause pellet press problems in the feed mill, while high feed  $a_w$  at the farm level is likely to result in feed quality issues (for example, disintegration of pelleted feed, microbiological deterioration).

Although a high moisture content is very unlikely to occur in whole batches of commercial feed, it may occur in material 'hanging up' in uncleanable pockets within protected niches within the processing environment. Steam addition during pelleting may also result in condensation on mill surfaces (Jones 2011). Moisture is removed from pellets using pellet cooler systems; as discussed in Section 2.3.1, cooler systems are among the highest risk sites in feed mills for *Salmonella* contamination and growth. In one study, *Salmonella* isolation rates from the cooler were as high as 86% (Davies and Wray 1997), and *Salmonella* were also isolated from the cooler in more recent studies (Table 15, Appendix A.3).

*Salmonella* may form a biofilm in these niches when conditions are favourable, which facilitates persistence under less favourable conditions, and provides protection against environmental stresses such as disinfection (Vestby et al. 2009, Habimana et al. 2010, Prunic et al. 2016). One study reported a correlation between the persistence of *Salmonella* strains in feed mills with their ability to form a biofilm (Vestby et al. 2009). Feed mill isolates of the serotypes *S. Agona* and *S. Montevideo* were good biofilm producers and persisted for several years in Norwegian feed mills (Nesse et al. 2003, Vestby et al. 2009). *S. Senftenberg* strains persisted for a shorter period in feed mills and were medium biofilm producers. However, *S. Typhimurium* isolates were not observed to persist and were relatively poor biofilm producers. Non-*Salmonella* microflora that are resident in feed mills may also produce biofilms, which has been shown to have a protective effect on any *Salmonella* present (Habimana et al. 2010). *Salmonella* isolates from rendering plant equipment were also found to be capable of forming strong biofilms, which was hypothesised to be an important factor contributing to *Salmonella* contamination of rendered product (Gong and Jiang 2017).

#### 2.4.2 Survival

Although growth is not likely to occur in dry feed, *Salmonella* can survive for extended periods under dry conditions (Appendix A.1). *Salmonella* numbers decrease over time, so the survival times depend on the numbers of *Salmonella* present to begin with. Experiments that assess survival typically inoculate feed with significantly higher numbers of *Salmonella* (for example, up to 8-log<sub>10</sub> CFU/g of feed) than might be present during natural contamination scenarios (for example, up to 79.4 MPN/g reported in the previous Risk Profile (Cressey et al. 2011)). Laboratory incubation conditions may also not represent natural storage conditions. Therefore, experimental studies might overestimate actual survival times. Survival times are also influenced by the food type and storage conditions.

Earlier studies that examined *Salmonella* survival in animal feed, as discussed in the 2011 Risk Profile (Cressey et al. 2011), are summarised below. These show that *Salmonella* survives better under dry, cool conditions:

- Four serotypes of *Salmonella* (*S. Enteritidis* PT4, *S. Typhimurium*, *S. Mbandaka* and *S. Senftenberg*) survived for at least 26 months in commercial poultry meal after storage under ambient temperatures and normal atmosphere, although there was an approximately 5-log reduction in the number of recoverable cells over this time (Davies and Wray 1996).
- *S. Typhimurium* that had been inoculated on pelletised poultry feed survived longer at lower temperatures; at least 18 months at 11°C, 16 months at 25°C and 40 days at 38°C (although the relative humidity also differed by storage temperature) (Williams and Benson 1978).
- For *S. Senftenberg* that had been inoculated into chick starter feed and stored at 4°C for two weeks, there was an initial decline in numbers over the first few days, followed by a period where the number of recoverable cells remained almost constant (Liu et al. 1969). Increasing the moisture content of feed resulted in a more rapid decline in *Salmonella* numbers.
- *S. Montevideo* and *S. Heidelberg* in poultry feed and meat and bone meal declined faster at a higher  $a_w$  (0.75) than lower  $a_w$  (0.43 or 0.52) (Juven et al. 1984). *S. Montevideo* viable numbers reduced more slowly than *S. Heidelberg*.
- Survival *S. Oranienburg* and *S. Senftenberg* in fishmeal was increased at lower  $a_w$ , lower temperatures and under a nitrogen atmosphere (Doesburg et al. 1970).

Studies published since 2011 are consistent with the previous findings, as discussed below.

Five strains of monophasic *S. Typhimurium* 4,[5],12:i- were inoculated onto weaner pig feed, either with or without inclusion of sodium butyrate (0.3%) and stored at 10°C for 28 days (Burns et al. 2016). The initial level of the serotype in the feed was approximately 4 log<sub>10</sub> CFU/g. Across the five strains, only modest decreases in *Salmonella* numbers were seen in sodium butyrate-treated and untreated feed (<1 log<sub>10</sub> CFU/g).

*S. Enteritidis* was inoculated onto an all-flock poultry mash, which was maintained at room temperature for 14 days (Jeffrey et al. 2022). *Salmonella* numbers decreased steadily from 6.3 log<sub>10</sub> CFU/g at day 0 to not detectable at day 14. Decreases in the *Salmonella* numbers were significant between each measured time point (0, 1, 2, 7 and 14 days).

A collection of 37 *Salmonella* strains of 16 different serotypes (that did not include *S. Enteritidis*) were initially screened for desiccation tolerance by determining survival in soybean meal after 18 hours at 25°C (Norberto et al. 2022). The number of recoverable cells reduced by between 0.6 and 2.3 log<sub>10</sub> CFU/g. The highest tolerance (lowest reduction) was seen for strains of *S. Havana*, *S. Rugosa* and *S. Schwarzengrund*. However, there was substantial variability between different strains of the same serotype. Three strains with high desiccation tolerance (*S. Typhimurium*, *S. Havana* and *S. Schwarzengrund*) were then wet- and dry-inoculated onto soybean meal and held at 25 or 37°C. The inoculation method did not influence survival but both serotype and storage temperature influenced survival. Survival data were fitted to a Weibull model and the time to the first decimal reduction (1 log<sub>10</sub> CFU/g) was determined. At 25°C, 21-51 days were required for a 1 log<sub>10</sub> CFU/g reduction in numbers. *S. Havana* and *S. Schwarzengrund* had longer first decimal reduction times than *S. Typhimurium*. At 37°C, first decimal reduction times were in the range 2.7 to 7.9 days.

Soybean meal is a common ingredient in compound animal feed. Soybeans were inoculated with a suspension of *S. Senftenberg* 775W to give a final level of approximately 5 log<sub>10</sub> CFU/g and were stored at 20, 30 or 37°C (Rocha et al. 2022). Survival kinetics were modelled using the Weibull model. Decimal reduction times decreased with increasing temperature, from 5.6 days at 20°C, to 1.6 days at 30°C and 0.3 days at 37°C. The corresponding times for a 4-log<sub>10</sub> reduction were 71.1, 20.7 and 4.0 days, respectively.

A further study examined the persistence of *S. Enteritidis*, *S. Infantis* and *S. Typhimurium* that had been inoculated at high numbers (8 log<sub>10</sub> CFU/g) onto dietary plant fat, broiler feed and broiler feed supplemented with fat at a ratio of 1:10 fat:feed). The feed was kept under conditions that simulated four broiler production cycles (fluctuating temperature of 20-35°C; 147 days) (Ahmed et al. 2023). All strains survived better in feed (with or without fat), than the fat alone. Strains were detected in the feed samples after 147 days, but numbers had decreased by at least 6-log over this period (as determined by MPN/g).

## 2.4.3 Death

### Heat treatment

Heat treatment is one of the most effective methods used during feed manufacture to ensure the microbial safety of feeds. Heat is applied during rendering of animal product that may be used as an ingredient in feed manufacture, and also at the feed mill.

Heat treatment during rendering: Thermal inactivation of *Salmonella* in meat (as defined by New Zealand Import Risk Analyses in chicken and duck meat) requires 55°C for 1 hour, 60°C for 15-20 minutes, or 74°C for 15 seconds (Ministry for Primary Industries 2021c). Rendering

of animal product may involve either wet or dry application of heat (Meat Research Corporation and Australian Meat Technology 1997).<sup>41</sup> Dry rendering involves heating raw material to 105-140°C (using steam that is confined to a jacket surrounding the tank) until most of the water has evaporated, and the solid material is pressed or centrifuged to remove the fat from the protein and other solid material. Wet rendering involves direct steam injection where some of the water is removed mechanically and the remainder thermally. Wet rendering can be conducted at high (temperature range 90-140°C) or low temperatures (temperature range 60-95°C). Low-temperature rendering results in tallow that is of a higher quality and the process is more energy-efficient.

The rendering process is more complex than laboratory simulation experiments, but laboratory experiments provide an indication of how *Salmonella* might behave under different rendering parameters.

The efficacy of thermal activation of *Salmonella* during rendering of poultry material is an important consideration for understanding the risk posed by *S. Enteritidis* from chicken products entering into food-producing animals via feed, relevant to RMQ2. A study investigated the inactivation of a cocktail of *Salmonella* serotypes (*S. Senftenberg*, *S. Enteritidis* and *S. Gallinarum*) that had been inoculated onto raw poultry offal and heated for up to 15 minutes (Jones-Ibarra et al. 2017). Mean D-values (the time required to achieve a 1 log reduction in the microbial numbers at a defined temperature) were  $0.25 \pm 0.05$ ,  $0.17 \pm 0.01$ , and  $0.09 \pm 0.00$  minutes at 65.5, 68.3 and 71.1°C, respectively. When tested individually, *S. Senftenberg* was the most heat-tolerant. Mean D-values at 60°C were 0.41, 0.89 and 3.48 minutes for *S. Gallinarum*, *S. Enteritidis* and *S. Senftenberg*, respectively. The authors reported that a 7.0-log inactivation of *Salmonella* may be obtained after holding times of 1.78, 1.21 and 0.60 minutes during the rendering of raw poultry offal at temperatures of 65.5, 68.3, or 71.1°C; a 7.0-log inactivation is based on US Department of Agriculture (USDA) requirements for fully cooked poultry products (United States Department of Agriculture and Food Safety and Inspection Service 1999).

The fat content can affect the time until bacterial inactivation occurs. Increasing the fat content of beef from 7 to 24% resulted in an increase in the lag time for thermal inactivation, but a decrease in the D-value (Juneja and Eblen 2000). Another study examined thermal inactivation of *Salmonella* during rendering of high-fat beef trimmings treated under “worst-case scenario” commercial rendering conditions (Ramirez-Hernandez et al. 2018). A cocktail of five serotypes (*S. Senftenberg*, *S. Enteritidis*, *S. Newport*, *S. Typhimurium* and *S. Heidelberg*) were inoculated onto raw material with either 20 or 50% fat content. Incubation temperatures for 20% fat material ranged from 60-95°C; selected D-values were 4.17, 0.24, 0.36 and 0.29 minutes for 60, 75, 85 and 95°C, respectively. High-fat (50%) material was incubated at 100-121°C; selected D-values were 0.24, 0.16 and 0.10 minutes for 100, 113 and 121°C, respectively.

Heat treatment in feed mills: The production of good quality pelleted feed also includes a high-temperature conditioning (via steam), followed by passing of the feed through a die to form a pellet. The temperature increase during conditioning is achieved through steam injection. The friction involved in the pelleting process instantly raises the temperature of the feed by a further few (3-6°C) degrees (European Food Safety Authority 2008). Pelleting has been reported to involve temperatures between 70-90°C. New Zealand feed mills have reported minimum meal temperatures during conditioning of 80°C, with 90°C achieved under optimum conditions (input feed moisture content, steam quality) (Lake et al. 2005). New Zealand feed mills also reported

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<sup>41</sup> <https://mia.co.nz/assets/Uploads/Dunn-Rendering-Systems-in-NZ-2020.pdf>; accessed 7 August 2023

a conditioner residence time of 90 seconds. Although it was recognised that individual meal particles would have residence times normally distributed around this value, the reported range is 90 seconds plus or minus 12 seconds (Lake et al. 2005). In another study, heat treatments reported by one New Zealand feed mill for poultry and pig feed included steam (above 68°C) prior to pelleting, while another reported that the pellet press step was conducted at 80°C or 85°C for 30 seconds for dairy calf or poultry feed, respectively (Rivas 2016). While higher temperatures or longer treatments would result in higher levels of inactivation of microbial pathogens, high temperatures can affect the nutritional quality of the product (Abdollahi et al. 2013, Perera et al. 2021). As such, pelleting temperatures are primarily designed to provide a balance between nutritional and pellet quality of the feed.

The effectiveness of heat treatment for *Salmonella* inactivation may be influenced by the particle size and composition of the feed, for example, the fat content, moisture levels and acidity.

In general, variations in composition that decrease the availability of water will increase the thermal tolerance of the organism. For example, the D-value for *S. Senftenberg* at 71°C was 16.0 minutes with 5% moisture and 6.6 minutes at 10% moisture in meat and bone meal (Liu et al. 1969). In another study, thermal inactivation increased with temperature and with increasing moisture content of the feed (Himathongkham et al. 1996). Based on their data, a heat treatment at 85°C for 90 seconds would produce a 4-log reduction in *Salmonella* where the moisture content of the feed is 15%. Using this model, the optimum conditions achieved in New Zealand feed mills (90°C for 90 seconds) would be expected to achieve an approximate 4.6-log reduction in *Salmonella* numbers at 15% moisture. Although this is less than the 7-log reduction required by the USDA, it would be relevant for the low levels of *Salmonella* contamination likely to be present.

In more recent studies, a standard pelleting protocol (70°C) was compared to a thermally aggressive protocol (80°C) for reducing the numbers of the *Salmonella* surrogate *Enterococcus faecium* in a feed formulation dominated by corn (58%) and soybean meal (31%) (Boltz et al. 2019). The *E. faecium* strain used has a similar heat tolerance as more heat-tolerant strains of *Salmonella* such as *S. Agona* (Steghöfer et al. 2021), but is non-pathogenic, so can be tested in actual feed production settings. The standard and thermally aggressive pelleting protocols resulted in 3 and 4 log<sub>10</sub> reductions in *E. faecium* numbers (starting numbers were ~5 log<sub>10</sub> CFU/g), respectively. The higher pelleting temperature also increased pellet durability.

The thermal inactivation of *S. Typhimurium* in mash broiler feed (predominantly corn and soybean) was investigated at temperatures in the range 75 to 95°C and for heating times of 0 to 180 seconds (Boltz et al. 2021). Inactivation D-values were determined using either a linear or Weibull model. For temperatures of 75, 80, 85, 90 and 95°C, D-values from the linear model were 24.4, 13.9, 12.1, 8.8, 6.7 seconds, respectively. Corresponding D-values from the Weibull model were 7.6, 4.7, 4.0, 3.7 and 2.3 seconds.

Although thermal tolerance data comparing different serotypes using feed as a matrix are limited, thermal tolerance in other matrices varies by the *Salmonella* serotype (Bucher et al. 2008, Lianou and Koutsoumanis 2013, Pye et al. 2023). One study examined the thermal tolerance in broiler mash feed of serotypes most commonly associated with livestock feed contamination (Steghöfer et al. 2021). Cocktails of three strains per individual serotype inoculated onto feed were tested. The experiment was conducted at 85°C and 11-12% moisture for ~30 seconds in a customised laboratory steam conditioner rig to better simulate conditioning during feed production. *S. Montevideo* and *S. Agona* were significantly ( $P < 0.05$ )

more heat-tolerant. Log CFU/g reductions were: *S. Mbandaka* >5.3, *S. Senftenberg* >5.3, *S. Tennessee* >4.9, *S. Montevideo* 2.4 and *S. Agona* 1.9. *S. Using* a customised autoclave apparatus, the D-values for the most heat-tolerant *S. Agona* strain at 12% moisture were 178.2 and 3.1 seconds at 65 and 85°C, respectively. At 19% moisture, D-values were 81.1 and 0.7 seconds at 65 and 85°C, respectively.

In another study, heat tolerance was tested for seven *Salmonella* isolates (the serotypes were not reported) from cereals and thermally treated ingredients of cattle feed (Amado et al. 2014). Experiments were first conducted in phosphate buffered saline (PBS) at 55, 57.5, 60, 62.5 and 65°C. Mean D-values in PBS ranged from 1.7 to 5.7 minutes at 55°C, decreasing to 0.22 to 0.66 minutes at 65°C. The thermal resistance of the most heat-tolerant strain was then tested on acid- and antibiotic-free pelleted cattle feed. On feed, D-values were 5.24 minutes at 55°C and 0.43 minutes at 65°C (note that two different models were used to calculate D-values and results varied slightly between models). The effect of cattle feed particle size was also tested on inactivation kinetics. Heat tolerance increased with increasing feed particle size, with a 1.6-fold greater D-value at 60°C in feed of a larger particle size, which is likely due to an increase in the time required for the diffusion of heat into the food particles.

It has been suggested that microbes from naturally contaminated feed may be more heat-tolerant because they are subjected to a range of biotic stresses (heat, cold, desiccation) selecting for heat tolerance, and thus may not behave the same as those used in the experiments on artificially contaminated feed (Williams 1981). However, Amado et al. (2014) found no relationship between heat tolerance and feed isolation source. Another study found that *S. Enteritidis* isolates from chicken meat and pelleted broiler feed had similar heat tolerance profiles (Bucher et al. 2008).

## Chemical treatments

A number of chemicals may be added to feed to control *Salmonella* contamination, including organic acids (acetic, propionic, citric, formic) and their salts, ethanol, formaldehyde and isopropyl alcohol. Chemical treatment of feed is not routinely used in New Zealand, but may be employed in feed mills or rendering plants when a persistent *Salmonella* contamination exists or when an avian pathogenic *Salmonella* is isolated (for example, *S. Enteritidis*). Products reported to be used in chicken feed include organic acid formulations such as SalCURB™ (blend of aqueous formaldehyde 37% solution and propionic acid)<sup>42</sup>, or *Salmonella*-binding agents, such as the mannanoligosaccharide product BioMos™,<sup>43</sup> which are added at the mixing stage. The degree to which different products are used could not be determined because feed ingredient specifications are proprietary.

Organic acid-based treatments: It is considered that organic acids exert their antibacterial effects through disruption of intracellular pH regulation (Van Immerseel et al. 2006). There is also evidence that organic acids interfere with expression of virulence genes, reducing intestinal invasion (de Jonge et al. 2003, Van Immerseel et al. 2006). However, there are also concerns that the use of organic acids may lead to the selection of acid-tolerant strains, which may be better able to survive gastric acidity in humans (de Jonge et al. 2003).

Based on studies discussed in the 2011 Risk Profile (Cressey et al. 2011), acid decontamination was not as effective as heat decontamination for reducing *Salmonella* numbers. Reduction of *Salmonella* in feed by organic acids may take several days and it is possible that feed may have been consumed and colonisation established before sufficient

<sup>42</sup> <https://www.kemin.com/na/en-us/markets/animal/products/sal-curb>; accessed 4 August 2023

<sup>43</sup> <https://www.alltech.com/bio-mos>; accessed 4 August 2023

inactivation has had time to occur (Hinton and Linton 1988, Park et al. 2003, Carrique-Mas et al. 2007). However, there is evidence that organic acids provide a level of residual protection against post-production contamination/recontamination of feed (Rouse et al. 1988, Carrique-Mas et al. 2007). In addition, organic acids added to feed may create an intestinal environment less favourable for *Salmonella* colonisation in chickens (Rouse et al. 1988, Khan and Iqbal 2016, Bourassa et al. 2018, Aljumaah et al. 2020).

Samples of three feed materials known to be contaminated with *Salmonella* (soybean meal with *S. Tennessee* and *S. Montevideo* at 21 MPN/100 g, ground milk thistle seeds with *S. Give* at 240 MPN/100 g, and corn gluten with *S. Rissen* at 4600 MPN/100 g) were treated with each of five organic acid preparations<sup>44</sup> at inclusion rates of 1-7% for 1, 2 or 7 days at room temperature (Axmann et al. 2017). Treatment efficacy was determined by the number of 10 samples that were positive for *Salmonella*. Complete elimination of *Salmonella* (0/10 positive results) was only consistently achieved for product 2 (67.9% formic acid and 8.4% lactic acid) at an inclusion rate of 7%. Product 4 (37% formic acid/19% ammonium formate/8% sodium formate/18% propionic acid) also gave near complete elimination at 7% inclusion. Product 5 (38.5% formic acid/9% citric acid/7% lactic acid/7.5% propionic acid/0.5% benzoic acid) was largely ineffective at all inclusion rates and all time points. There were differences between feed materials but it is unclear whether the differences were matrix-, serotype- or concentration-related.

A series of experiments were conducted to consider the impact of different feed materials and different *Salmonella* strains on the ability of organic acids to control *Salmonella* in feed (Koyuncu et al. 2013). The studies involved:

- Four *Salmonella* strains; two considered to be acid tolerant (*S. Putten* and *S. Infantis*) and two considered to have low acid tolerance (*S. Typhimurium* and *S. Senftenberg*).
- Three feed materials; a pelleted compound pig feed, soybean meal and rapeseed meal.
- Four organic acid preparations; formic acid, formic acid/propionic acid (80:20), Amasil (61% formic acid, 20.5% sodium formate, 18.5% water) and Luprocid (75% formic acid, 25% propionic acid).

Different experiments were as follows:

- Rapeseed meal was inoculated with *S. Typhimurium* or *S. Infantis* and exposed to 1% formic acid or formic acid/propionic acid, followed by incubation at room temperature for up to 120 hours. No significant difference was seen between the two acid treatments. *Salmonella* numbers decreased by approximately 0.5 log<sub>10</sub> in the first hour, a further 0.5 log<sub>10</sub> after 48 hours and a further 0.5 log<sub>10</sub> after 120 hours.
- Amasil or Luprocid (0.9 or 1.5%) were added to pig feed or soybean meal inoculated with *S. Typhimurium* or *S. Infantis* and kept at room temperature for 28 days. A difference was observed between survival in the different feed types and different acid products, with the reduction 0.5-1.0 log<sub>10</sub> greater with Amasil than Luprocid at all time points in pig feed. The overall reductions in *Salmonella* numbers and the difference between acid products were less in soybean meal.
- Each strain was separately inoculated into each feed material and treated with 1% formic acid or formic acid/propionic acid and investigated after 1, 48 and 144 hours. Reductions

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<sup>44</sup> Organic acid preparations were: 63% formic acid and 35% lignin sulfonic acid, 67.9% formic acid and 8.4% lactic acid, 31.0% formic acid/24.5% ammonium formate/8% propionic acid, 37% formic acid/19% ammonium formate/8% sodium formate/18% propionic acid, and 38.5% formic acid/9% citric acid/7% lactic acid/7.5% propionic acid/0.5% benzoic acid.

in *Salmonella* numbers were in the order pig feed > rapeseed meal > soybean meal. No significant difference was seen between acid treatments.

- To refine the assessment of acid tolerance, *S. Typhimurium* and *S. Infantis* were inoculated into pig feed treated with 1% formic acid and assessed at 1, 48 and 144 hours. Reductions in the numbers of *S. Typhimurium* were greater than for *S. Infantis*, with a difference of about 0.5 log<sub>10</sub>, relative to the control, at 48 and 144 hours.
- *S. Typhimurium* and *S. Infantis* were inoculated into rapeseed meal and soybean meal containing 1% formic acid. Feeds were stored at 5, 15 or 23°C and assessed at 1, 48 and 120 hours. Reductions in *Salmonella* numbers significantly increased at higher temperatures.

Together, these experiments show that organic acids can decrease *Salmonella* survival but the effect depends on the feed type, *Salmonella* strain, and storage conditions.

Formaldehyde-based treatments: A number of studies have shown improved decontamination of *Salmonella* in feed or feed ingredients by formaldehyde when compared with organic acids (Duncan and Adams 1972, Smyser and Snoeyenbos 1979, Carrique-Mas et al. 2007, Cochrane et al. 2016). However, formaldehyde may be less effective in providing residual protection due to its volatility (Khan et al. 2003). Formaldehyde had previously been used in the EU to counteract contamination of feed, but its use became illegal in 2017 under Regulation (EU) 2018/183.<sup>45</sup> As noted above, formaldehyde is an ingredient in SalCURB™, which may still be used in New Zealand.

Other chemical treatments: A novel product for pathogen control in animal feed (Finio, phytochemicals and carboxylic acids) was compared to three existing products: Fysal (organic acids with their ammonium salts), SalCURB™ K2 (formic, lactic and propionic acid, salts and a surfactant; no formaldehyde) and Salgard SW (propionic acid and ammonium salts of propionic and formic acid) (Gosling et al. 2021). A commercial layer hen mash was treated with each of the biocides at final concentrations of 0.05, 0.10, 0.15, 0.20 or 0.25% for Finio and 0.3 or 0.6% for the other three products. Each treated mash was then blended with feed contaminated with *S. Typhimurium* DT104, with a final *Salmonella* level of approximately 1.4 x 10<sup>5</sup> CFU/g (5.1 log<sub>10</sub> CFU/g). After 24 hours at room temperature, ten subsamples of each preparation were analysed. No significant reduction in *Salmonella* numbers, relative to an untreated control, was seen for any of the three comparator products at 0.3% inclusion and no significant reduction was seen at either inclusion concentration for SalCURB™. Finio produced concentration-dependent reductions in the *Salmonella* numbers at all inclusion levels. Final mean *Salmonella* numbers ranged from 1.16 log<sub>10</sub> CFU/g (0.05% Finio) to 0.03 log<sub>10</sub> CFU/g (0.25% Finio), compared with 1.94 log<sub>10</sub> CFU/g in the untreated control.

Dry sodium bisulphate was added to an all-flock poultry mash at inclusion rates of 0.25, 0.50 and 0.70% (Jeffrey et al. 2022). Feed samples were inoculated with *S. Enteritidis* and maintained at room temperature for 14 days. The dry acidulant had no additional impact on the *Salmonella* numbers over time.

### Combination treatments

The efficacy of combination treatments on *Salmonella* inactivation in feed has also been investigated. To assess heat and organic acid combined, *Salmonella* isolates (serotype not stated) from vegetable or grain feed ingredients were inoculated at 5-6 log<sub>10</sub> CFU/g onto cattle feed that had been acidified with either formic or lactic acid (Amado et al. 2013). Final

<sup>45</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018R0183>; accessed 9 August 2023

concentrations of acid were in the range 0.02-0.2% volume/weight. Samples of the acid-treated *Salmonella*-inoculated feed were heated for 2 minutes at temperatures in the range 50-70°C. Heat had a greater effect on *Salmonella* survival than acid, and the effect of heat was strain-independent while sensitivity to acid was strain-dependent. After two minutes of heat treatment, optimal microbial inhibition was generally achieved at temperatures above 65°C, using 0.1% formic acid or 0.2% lactic acid.

A further study investigated nine commercial products that contained organic acids in addition to other components, on the survival of *S. Typhimurium* and *S. Enteritidis* on feed (Wales et al. 2013). Some of the blends had only modest anti-*Salmonella* activity (reducing *Salmonella* numbers to 0 or 1 log<sub>10</sub> units below negative control products that lacked organic acids). One product that contained formaldehyde, terpenes, surfactant and organic acid, was the most effective, exceeding reductions associated with other products by 1 to 3 log units at most time points.

### **Biological treatments**

Bacteriophages are viruses that specifically target bacteria as a host, causing cell death. Studies have trialled using bacteriophages as additives in poultry feed to reduce or prevent gastrointestinal colonisation of poultry by *Salmonella*. The high level of specificity of phages (often, specific to only a few serotypes or strains within a serotype) means that they are typically prepared as a phage mixture when intended for therapy (Gast et al. 2022a). Development of resistance and changing populations of *Salmonella* can limit the efficacy of phage therapy.

In one study, *S. Enteritidis* was inoculated into a corn-soy commercial broiler starter mash that contained either 0, 0.1 or 0.15% of a *S. Enteritidis*-specific bacteriophage preparation (Kimminau et al. 2020). The feed was given to groups of broiler chicks (90 birds/treatment) on days 8-14 of the trial. Cloacal swabs were taken for *Salmonella* testing on days 14 and 21 and caecal, spleen and liver samples were taken from euthanised chicks at 28 days. The prevalence of *Salmonella*-positive cloacal swabs was significantly lower in birds receiving bacteriophage-treated feed than control feed, but the greatest reduction was seen at the lower bacteriophage inclusion rate. The prevalence of *Salmonella*-positive cloacal swabs decreased in all groups between days 14 and 21, with an approximately 50% decrease in prevalence in both control and treatment groups. There was also a reduction in *Salmonella* MPN/swab from cloacal swabs for the lower bacteriophage concentration, but no significant differences between treatment groups for the *Salmonella* prevalence in the liver/spleen.

Further feed supplements include prebiotics and probiotics. Probiotics are direct-fed microbes for the purpose of competitive exclusion to impede *Salmonella* intestinal colonisation (Gast et al. 2022a). Although not specifically a biological treatment, prebiotics are nutrient mixtures that are utilisable by beneficial gut microbiota and promote their growth, thereby reducing *Salmonella* colonisation. Specifically, both probiotics and prebiotics have been shown to prevent or reduce *Salmonella* colonisation of broiler and layer chickens (Khan et al. 2020, Ricke et al. 2020, Gast et al. 2022a). Studies have demonstrated variable efficacy of probiotics in reducing colonisation of pigs (Yin et al. 2014, Barba-Vidal et al. 2017, Peeters et al. 2019).

#### **2.4.4 Cleaning practices in the feed mill environment**

As discussed in the 2011 Risk Profile (Cressey et al. 2011), the feed mill environment, including incoming raw materials, is essentially dry, allowing minimal scope for bacterial growth. The exception to this is the conditioner in which a significant amount of moisture in

the form of steam is introduced into the feed. However, the introduction of steam during this process would likely inactivate any vegetative bacteria such as *Salmonella*.

Crushing plants, where plant protein products such as soy meal are prepared, are also dry environments allowing minimal scope for bacterial growth.

In contrast, the rendering environment producing meat and bone meal contains both wet and dry environments, with associated wet and dry (physical removal) cleaning regimes. A major focus of rendering plant design is the strict separation of wet and dry areas. While the heating process during rendering is sufficient to destroy *Salmonella*, there is a risk of recontamination following heat treatment. Regular removal of any accumulated moist meal deposits (for example, edges of casings around augers) and thorough dry cleaning of the rendering plant reduces the risk of further contamination past the heat treatment step.

New Zealand feed mills and rendering plants rely on Good Manufacturing Processes and the implementation of hazard analysis and critical control point (HACCP) plans to control contamination (New Zealand Feed Manufacturers Association 2023b). Good Manufacturing Processes rely on appropriate facility design and layout that allows physical cleaning, guidelines for employee hygiene and effective pest management to limit the introduction of biological hazards into the facility. Cleaning of feed mills usually concentrates on the physical removal of loose and adhering material (Lake et al. 2005). Modern systems also implement dust control measures. Some operators have also reported the use of sanitisers in particular situations (in storage areas used for meat and bone meal following *Salmonella* detection). However, sanitation of surfaces is not always feasible due to the exclusive use of dry ingredients during manufacture, the lack of accessibility for cleaning equipment, prevalence of organic material or dust, and some sanitisers may corrode processing surfaces (Huss et al. 2015, Muckey et al. 2016). Internationally “sequencing” is often carried out, where feed types are manufactured in a strategic sequence to limit carryover from high-risk ingredients to specific feeds, as well as “flushing,” where a pulse of animal feed is conveyed through the manufacturing system to “flush” hazards through the manufacturing system. One study investigated the efficacy of flushing feed processing surfaces with treated and untreated feed for the control of *S. Enteritidis* in poultry feed and from surfaces (Muckey et al. 2020). Flushing reduced *S. Enteritidis* contamination from feed and feed mixing surfaces, with greater reductions after the second batch of feed processing or following flushing with feed containing an essential oil blend or a proprietary blend of medium-chain fatty acids.

### 3 EXPOSURE ASSESSMENT

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#### Key findings

- In New Zealand, *Salmonella* prevalence from poultry industry testing of feed materials and finished feed is in the range of 0.1-3.2% annually (2011-2022). Other available data show that *Salmonella* are also detected from meat and bone meal feed ingredients and from finished feed for non-poultry species.
- Certain serotypes are commonly observed as contaminants of animal feed and feed ingredients in New Zealand. Considering the isolates from different surveillance streams, the top five serotypes found in feed and feed materials from 2011 to 2022 were *S. Infantis*, *S. Mbandaka*, *S. Agona*, *S. Typhimurium* and *S. Havana*.
- *S. Enteritidis* has been isolated from New Zealand food-producing mammalian species yearly from 2011 to 2022, and since 2020 from poultry product and poultry environments. However, this serotype was not isolated from New Zealand livestock feed or feed ingredients during the period, and was not reported from feed in the 2011 Risk Profile. *S. Enteritidis* is also not a common contaminant of finished animal feed or from the feed mill environment in other countries, despite being commonly isolated from poultry.
- Available data from food-producing animals and animal products show that the highest numbers of *Salmonella* detections were from bovine species and bobby calf meat; but *Salmonella* testing programmes differ between sectors.
- The most common serotypes present in animal feed and feed ingredients are also commonly isolated from food-producing animals and their meat. Product from food-producing animals may also be used in the production of feed (noting that poultry meal is not fed to poultry and ruminant meal is not fed to ruminants). Therefore, the direction of transmission could occur from animal-to-feed or from feed-to-animal, and there are other transmission pathways by which infection of animals and contamination of feed can occur. Common serotypes from animal feed are also observed among human salmonellosis cases; however, human cases of *S. Mbandaka* and *S. Havana* were less common.
- Internationally, serotypes that are common contaminants of food-producing animal feed are more commonly observed in poultry flocks compared with other food animal sectors (although there are more surveillance programmes for *Salmonella* in poultry than for other sectors). This supports that transmission from contaminated feed to chickens is likely to occur for some serotypes.
- Exposure of humans to *Salmonella* in animal products depends on the level of contamination, how the product is cooked and handled to mitigate the risk, together with the volume consumed. Data from primary processing shows *Salmonella* prevalence values of 0% (ratites) to 1.18% (ducks and turkeys). There has been a 9.4% increase in meat consumption in New Zealand between 2011 and 2022. Although there have been decreases in the consumption of beef/veal (31.2% reduction) and mutton/lamb (40.7% reduction), these were more than offset by the increases in the consumption of poultry meat (35.9% increase) and pork (19.9% increase). Egg consumption has fluctuated since 2010. Of these animal products, eggs are most likely to be consumed raw or undercooked.

Assessing the exposure pathway of *Salmonella* to animals via the consumption of contaminated feed, and subsequently to humans when they eat the animal product, is complex. Factors influencing the exposure of animals to *Salmonella* are the prevalence and numbers of *Salmonella* contaminating raw feed ingredients, the type of feed ingredients (which differ by animal species feed), the prevalence and numbers of *Salmonella* contaminating the finished product, the serotypes present in the feed, and the volume (dose) of feed consumed by the different animal sectors and individual animals. The exposure of humans to salmonellosis from the consumption of contaminated product is influenced by the animal species from which the product arises, the amount consumed, the prevalence, numbers and serotype of *Salmonella* contaminating the product, and how the product is handled and prepared for consumption. In between these animal and human *Salmonella* exposure scenarios, there is a presumption that at least some of the animals consuming contaminated feed will become colonised or infected with *Salmonella*. Without this step, the chain of transmission will be broken. Aspects of these exposure variables are discussed in this section.

### 3.1 PREVALENCE OF *SALMONELLA* IN NEW ZEALAND FEED

#### 3.1.1 Testing programmes

When *Salmonella* contaminates a feed ingredient or finished feed, its distribution is expected to be heterogeneous. Therefore, samples collected for testing should be a representative composite of the feed type (New Zealand Feed Manufacturers Association 2023b). Because of this heterogeneity, testing might miss *Salmonella* present in the batch. Feed ingredients and finished feed are generally tested for presence/absence of *Salmonella*; not the numbers present.

The ESR Enteric Reference Laboratory (ERL) receives isolates of *Salmonella* for typing from laboratories which have isolated them from non-human samples, including food products, animal feed, and food production environments. Of the non-human *Salmonella* isolates received by the ESR ERL from 2011 to 2022, 769 isolates were derived from the categories non-poultry feed (66 isolates), poultry feed (207 isolates), or the feed component meat and bone meal (496 isolates) (Table 8; Appendix A.3). There was a decrease in *Salmonella* isolations from feed-associated samples over time, with 196 isolations in 2011 down to nine isolations in 2022. Note that the number of feed samples tested per year is not provided; hence, caution must be taken when comparing data from year-to-year, or between feed categories.

The New Zealand poultry industry carries out an ongoing programme of testing of finished poultry feed and feed sources for the presence of *Salmonella* (Section 5.1, Table 9, Appendix A.2). The results are published annually in MPI's *Surveillance* biosecurity magazine.<sup>46</sup> Over the twelve-year period 2011-2022, *Salmonella* were detected in 469 of 45,438 (1.0%) of finished feed and feed source samples. Prevalence ranged from 0.1% (1 of 1,538 samples) in 2014, to 3.2% (103 of 3,232 samples) in 2017. However, it is likely that this programme includes a mixture of random and targeted samples.

There are no data available on the prevalence and serotypes of *Salmonella* from imported feed ingredients and finished product. Imported feed has the potential to contain novel *Salmonella* serotypes. However, the similarity in serotypes present in feed ingredients in New Zealand and internationally suggests that the risk of this occurring is probably quite low.

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<sup>46</sup> <https://www.mpi.govt.nz/biosecurity/exotic-pests-and-diseases-in-new-zealand/surveillance-programmes/surveillance-biosecurity-magazine/>; accessed 17 July 2023

Depending on the country of origin, international strains might have a higher rate of antimicrobial resistance than that encountered in New Zealand.

### 3.1.2 Product surveys

A pilot survey of finished ruminant and poultry feed was carried out in 2014-2015 (Rivas 2016). A total of 58 feed samples were obtained from 15 feed mills throughout New Zealand and analysed to determine the prevalence of *Salmonella*, *Listeria monocytogenes*, *Campylobacter* and Shiga toxin-producing *Escherichia coli* (STEC). *Salmonella* were detected in three ruminant feeds (3/58, 5.2%) from two different feed mills. It should be noted that the analytical samples were composites and the actual prevalence of *Salmonella* in feed samples is likely to be lower. *S. Agona* (a serotype reported previously in cases of foodborne illness in New Zealand) and *S. Orion* (a serotype that causes very few illness in New Zealand) were the only two *Salmonella* serotypes isolated from samples.

### 3.1.3 On-farm testing at New Zealand layer farms

A 2016 cross-sectional survey of New Zealand egg layer farm environments tested farm-level feed from 28 farms for *Salmonella* (Kingsbury and Soboleva 2019, Kingsbury et al. 2019). The 28 farms represented 20% of the total egg producers, and contained 46.0% of total laying hens (1.60 million of 3.48 million) in New Zealand at the time. One 25 g sample was tested per farm, except for farms where more than one feed type was in use for flocks sampled.

Of the 33 samples tested, a single feed sample (1/33; 3.0%) tested positive for *Salmonella*. While the survey aimed to access feed samples from the feed silo where possible, the positive feed sample was obtained from the feed trough in the laying shed. Three other environmental samples collected from that shed (dust, faeces and manure belt swab) also tested positive for the same, genetically related serotype, *S. Thompson*. Therefore, the feed may have become contaminated within the laying shed environment.

The positive feed sample was from a farm that produces its own feed. Seven other farms in this survey also produced their own feed. Self-produced feed has been reported to have a higher risk of *Salmonella* contamination than dedicated feed mills due to higher quality control and biosecurity procedures during manufacture at the feed mills (Davies and Wales 2010). The feed type was mash, which was also used by most of the farms in the survey (15/28), while twelve farms used crumbles (including three farms that also used mash), and four farms used pellets. *Salmonella*-inhibitory heat-treatment, which is a part of the feed pelleting/crumble manufacture process, was not used on any mash feeds in this survey. For this reason, other studies have found mash feed more likely to be contaminated than pellet feed (Jones and Richardson 2004, Jones 2011). However, a *Salmonella* inhibitor was added to most mash feeds in this survey (including the positive sample source). Four farms used feed that, to their knowledge, did not undergo *Salmonella*-inhibitory treatments; however, all farms indicated feed was tested for *Salmonella* by the manufacturer.

## 3.2 SEROTYPES FROM FOOD-PRODUCING ANIMAL FEED

*Salmonella* serotype data for ESR ERL typing of non-poultry feed (66 isolates), poultry feed (207 isolates), or the feed component meat and bone meal (496 isolates) are provided in Table 8 (Appendix A.2). For these three sample types, 13 serotypes were identified at least ten times during the 2011 to 2022 period. The most frequently observed serotype from ESR ERL data

was *S. Infantis* (154 detections from 769 feed-related isolates; 20.0%), which was most commonly isolated serotype from meat and bone meal (128 of the 496 detections; 26.0%). The second most common serotype was *S. Agona* (85 detections from 769 feed-related isolates; 11.1%).

A further data source for *Salmonella* serotypes in poultry feed is annual data from the poultry industry, as reported in the *Surveillance* biosecurity magazine.<sup>47</sup> There is some overlap between this data stream and the ESR ERL reporting, but many isolates serotyped by poultry laboratories are not sent to ESR ERL for further typing, and thus not included in the ESR ERL surveillance reporting. For the period 2011 to 2022, the most common serotype isolated was *S. Mbandaka* (123 detections from 469 isolates; 26.2%), followed by *S. Typhimurium* (41 detections; 8.7%) (Table 9, Appendix A.2). The serotype proportions differed between ESR ERL poultry feed and poultry industry data. It should be noted that 81/123 poultry industry detections of *S. Mbandaka* occurred in the 2017 year and likely relate to a specific contamination issue.

Most of the serotypes isolated more than ten times from poultry and non-poultry feed and/or meat and bone meal from 2011 to 2022 (Table 8 and Table 9; Appendix A.2), were also commonly isolated from New Zealand poultry feed and meat and bone meal for the period 2004 to 2007, as reported in the 2011 Risk Profile (Table 6 of that report; Cressey et al. 2011). *S. Fresno* was the only serotype not identified during the earlier period. From the earlier period, the top three serotypes for poultry feed were *S. Derby*, *S. Typhimurium* and *S. Brandenburg*. For meat and bone meal, the top serotypes were *S. Anatum*, *S. Infantis* and *S. Brandenburg*.

For the time period assessed, *S. Enteritidis* was not isolated from animal feed from either of the surveillance reporting mechanisms. *Surveillance* magazine reported that technical advice from Animals and Aquatic Risk Analysis Team was provided in response to *S. Enteritidis* in poultry feed from Australia in March 2020 (Ministry for Primary Industries 2020). However, this was in response to a 2018 outbreak of *S. Enteritidis* in Australia associated with layer chickens rather than any detection of *S. Enteritidis* in feed; the risk was deemed to be low (but not negligible) (Kate Thomas, MPI, pers. comm., August 2023). *S. Enteritidis* was also not reported from livestock feed or feed ingredients in the 2011 Risk Profile (Cressey et al. 2011).

### 3.3 PRODUCT RECALLS

There are two kinds of recalls of animal feed that might occur; voluntary and directed (Awilda Baoumgren, MPI, pers. comm., August 2023). The more common approach is a voluntary recall, which the company initiates, either as a matter of good product stewardship or in order to address a potential or known breach of the *Agricultural Compounds and Veterinary Medicines Act 1997*<sup>48</sup> regulations. A directed recall is one that is initiated under Section 35G of this Act, where the Director-General has determined that the issue with the feed breaches the Act and poses a risk to animal welfare, public health, or trade. The trigger for an animal feed recall related to *Salmonella* would be related to a breach of Regulation 7 of the Act, regarding fitness for purpose, and whether the contaminated product is able to be harmful to the animal consuming the feed (7(d) and (f)).

As discussed in Section 5.1, the *Manufacture of Animal Feeds in New Zealand - Code of Practice* details procedures for traceability and recall of animal feed. No data were found on

<sup>47</sup> <https://www.mpi.govt.nz/biosecurity/about-biosecurity-in-new-zealand/surveillance-biosecurity-magazine/>; accessed 2 March 2023

<sup>48</sup> <https://www.legislation.govt.nz/act/public/1997/0087/latest/DLM414577.html>; accessed 9 August 2023

the number of animal feed recalls as a result of positive *Salmonella* test results. Note that due to the time taken for *Salmonella* testing of feed (typically, sampling followed by four days following receipt by the laboratory), feed may have already been consumed by animals before a positive result has been returned (Kerry Mulqueen, PIANZ, pers. comm., June 2023). It is possible that bagged product could be recalled. An option for treating *Salmonella*-positive feed is an additional heat-treatment to inactivate *Salmonella*.

### 3.4 PREVALENCE AND SEROTYPES OF *SALMONELLA* FROM FOOD-PRODUCING ANIMALS AND FOOD PRODUCT IN NEW ZEALAND

In order to consider the likely contribution of animal feed to *Salmonella* contamination in food-producing animals and the onward transmission to humans, it is necessary to consider the level of *Salmonella* contamination in the food product from food-producing animals in New Zealand. Note that because rendered product from food-producing animals may also be used in the production of feed, the direction of transmission may also occur in the direction of livestock to feed. There are other transmission pathways by which *Salmonella* contamination of feed by food production animals can occur, such through effluent application to crops.

As discussed in Appendix A.2.2, ESR ERL collates data on non-human *Salmonella* isolates that arise from different testing programmes and mechanisms; for example, sick animals, the NMD programme, the production environment and outbreak investigations. As such, there are biases for the types of data obtained. The data were reviewed to explore whether *Salmonella* serotypes commonly identified in animal feed were also commonly isolated from food-producing animals. The frequency by which the most common serotypes from animal feed and feed materials were isolated from food-producing species is shown in Table 10 (Appendix A.2). Serotypes found in animal feed were frequency isolated from food-producing species. For mammalian species (predominantly cattle, as well as sheep, pigs, goats and deer), the overwhelming majority were *S. Typhimurium* (2,912 isolates of the 4,384 common feed serotypes; 66.4%) followed by *S. Brandenburg* (1,009 isolates; 23.0%). For poultry, the most common serotype was also *S. Typhimurium* (247 of the 617 common feed serotypes; 40.0%), followed by *S. Mbandaka* (84 isolations; 13.6%). Common feed isolates accounted for 5,001 of the 7,498 total isolates for mammalian food-producing species (66.7%) and 617 of the 1,109 total isolates for poultry (55.6%). The data support that transmission from feed to animals could be occurring, but without epidemiological data showing transmission from feed to animals, the above findings only indicate that this might be occurring. Interestingly, the second most common serotype from mammalian livestock over the same time period was *S. Bovismorbificans* (1,466 isolations),<sup>49</sup> which was not detected in feed.

There were no data identified for *Salmonella* isolated from dairy products and eggs in New Zealand since 2011. The main source of data for *Salmonella* prevalence from animal meat is via National Microbiological Database (NMD) Programme. NMD data for *Salmonella* prevalence from poultry carcasses (meat chicken, end-of-lay (EOL), duck and turkey) are presented in Table 11 (Appendix A.2). *Salmonella* prevalence from meat (broiler) and EOL chicken carcasses following primary processing remains very low (less than 1% of chicken carcasses overall, and less than 0.1% of meat chicken carcasses yearly from 2015 to 2022). Prevalence in duck and turkey samples was modestly higher with 1.18% of samples testing positive from 2016 to 2022 (16 of 1353 samples tested).

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<sup>49</sup> <https://www.esr.cri.nz/our-research/nga-kete/infectious-disease-intelligence/enteric-reference-testing/non-human-salmonella-isolates/>; accessed 30 August 2023

*Salmonella* prevalence from NMD programme testing of red meat samples (bobby calf, non-bobby bovine, caprine and ratite) over the period 2011 to 2022 is presented in Table 12 (Appendix A.2). Of the red meat sample types, the highest *Salmonella* prevalence was from bobby calf carcasses, bulk meat and primal cut samples (167 of 39,340 samples; 0.42%). Prevalence remained stable over the period assessed. There were only four isolations from bovine fresh carcass and bulk meat samples (of 13,668 samples tested; 0.03%), and three from caprine samples (of 4,019 samples tested 0.07%). There were no detections from ratite samples (out of 293 samples tested).

*Salmonella* serotypes of isolates from the NMD programme samples are shown in Table 13 (Appendix A.2). The most common serotype was *S. Brandenburg* (66 of 229 tested; 29%), all but one of which were from bobby samples. This serotype was also the most common from feed samples; particularly of the meat and bone meal source category (Table 8; Appendix A.2). Therefore, it is possible that the beef was the responsible for *S. Brandenburg* contaminating the meat/bone meal.

The second-most prevalent serotype from NMD programme samples was *S. Typhimurium*, which was the second most common serotype from poultry industry feed data (Table 9; Appendix A.2), and fifth most common from ESR ERL feed data (Table 8; Appendix A.2). Eight of the 11 serotypes isolated from any poultry NMD programme sample, were also among the *Salmonella* serotypes isolated at least ten times from poultry feed (Table 8 and Table 9, Appendix A.2). Results are consistent with poultry feed acting as a source for contamination of poultry flocks; further support for this could be obtained from finer typing of isolates such as by WGS. One of the exceptions was *S. Enteritidis*, which was only isolated on three occasions from NMD programme samples. As noted earlier (Section 3.1), *S. Enteritidis* has not been isolated from any feed samples for the period assessed.

Since the previous Risk Profile, no new prevalence or serotype data was found for *Salmonella* in foods of animal origin at retail in New Zealand.

Common serotypes from both feed and from food-producing animals and their meat, are also observed from human cases of salmonellosis (Section 4.2). Five of the common feed serotypes (*S. Typhimurium*, *S. Brandenburg*, *S. Infantis*, *S. Agona* and *S. Montevideo*) are amongst those that have caused 50 or more human cases during the period 2011 to 2022 (Table 6). Two of the top five serotypes from animal feed and ingredients, *S. Mbandaka* and *S. Havana*, were observed less frequently from human salmonellosis cases. Of the 12,349 human cases of salmonellosis from 2011 to 2022, there were 47 cases of *S. Mbandaka* and seven of *S. Havana*.

### 3.5 CONSUMPTION OF MEAT AND ANIMAL PRODUCTS IN NEW ZEALAND

The amount of meat and other animal products consumed in New Zealand is relevant for considering the flow-on effect from introduction of *Salmonella* into food-producing animals for human exposure.

Based on industry data, the amount of poultry meat produced in New Zealand has increased 1.5-fold since 2011 (Kingsbury 2023a).<sup>50</sup> There has also been an increase in poultry consumption since 2011 (34 kg/person/year), reaching a peak of 47.0 kg/person/year in 2019,

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<sup>50</sup> <https://www.pianz.org.nz/>; accessed 18 July 2023

which represents a 1.4-fold increase in consumption. However, the increased consumption did not appear to have increased the risk of salmonellosis as indicated by notification rates.

There had been an 22.1% decrease in total meat consumption in New Zealand from 2000 (86.7 kg/capita) to 2011 (67.6 kg/capita), as calculated from New Zealand consumption data from Organisation for Economic Cooperation and Development (OECD).<sup>51</sup> The overall decrease was due to a dramatic decrease in mutton/lamb and beef/veal consumption. There has since been a 9.4% increase in total meat consumption (to 73.9 kg/capita in 2022), which reflects increases in both poultry and pork consumption. OECD data for the years 2000, 2011 and 2022 were as follows:

- Pork:
  - 2000: 13.4 kg per capita,
  - 2011: 16.0 kg per capita,
  - 2022: 19.2 kg/capita. Industry data reported that 36.2% of the 2022 volume was New Zealand-raised, the remainder is imported.<sup>52</sup>
- Lamb and mutton:
  - 2000: 25.5 kg per capita,
  - 2011: 5.6 kg per capita,
  - 2022: 3.3 kg per capita.
- Beef and veal:
  - 2000: 23.3 kg per capita,
  - 2011: 16.5 kg per capita,
  - 2022: 11.4 kg per capita.
- Poultry:
  - 2000: 24.6 kg per capita,
  - 2011: 29.5 kg per capita,
  - 2022: 40.1 kg per capita.
- No data were found on venison, goat, emu or ostrich consumption.

The 2008/2009 New Zealand Adult Nutrition Survey collated data on food consumption from a study population, which was then extrapolated to the adult population aged 15 years and over. The data showed that a majority of the adult population (94.5%) had consumed red meat in the past four weeks from when the survey was undertaken (University of Otago and Ministry of Health 2011). Red meat was eaten one to two times per week by 30.1% of the adult population and three to four times per week by 45.4%.

Egg consumption in New Zealand has fluctuated since 2010, reaching an estimated peak of approximately 250 eggs per person per year during 2020 (Kingsbury 2023b).<sup>53</sup> Data on egg consumption from New Zealand nutrition surveys from 2002 and 2009 indicate that at that time, almost half of the population consumed egg(s) on any given day (Ministry of Health 2003, University of Otago and Ministry of Health 2011). Most servings of eggs were cooked but consumption of raw egg was reported by some respondents. The data do not provide information on the nature of egg cooking (such as times/temperatures or egg appearance, for example, “runny”, “soft boiled”).

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<sup>51</sup> <https://data.oecd.org/agroutput/meat-consumption.htm>; accessed 6 October 2023. Meat consumption was measured in kg of retail weight per capita.

<sup>52</sup> <https://www.nzpork.co.nz/about-us>; accessed 18 July 2023

<sup>53</sup> <https://www.eggfarmers.org.nz/egg-farming-in-nz>; accessed 18 July 2023

### 3.6 COMMENTARY ON DATA FROM OTHER COUNTRIES

A European assessment concluded that in regions with low *Salmonella* prevalence in food-producing animals, *Salmonella* contaminated feed represents a major source for introduction of *Salmonella* into the food production chain, while in regions with high prevalence the relative importance of contaminated feed is difficult to quantify (Panel on Biological Hazards, 2008).

A summary of overseas studies on the prevalence of *Salmonella* in animal feed ingredients and compound animal feed is provided in Table 14 (Appendix A.3). Overseas data indicate temporal and regional trends in the prevalence of *Salmonella* contamination in finished feed and feed ingredients. Of the feed ingredients, the highest prevalence was observed from fish meal and animal meat and bone meal (as high as 84% and 48%, respectively) (Table 14). Contamination of plant-based material ingredients was also frequently reported, with prevalence as high as 22% from cottonseed, 18% from canola meal, 16% from soybean meal and 14% from sunflower meal. Prevalence was typically lower in finished feed product. While the 2011 Risk Profile reported that earlier studies often observed *Salmonella* in greater than 10% of some product types, data post-2000 rarely include prevalence figures for *Salmonella* in excess of 10%. The exceptions were poultry feed from Kenya (17-38% prevalence) and Nigeria (37.5% prevalence), and some “ready-to-eat” feed from the US (0-30% prevalence). The reasons for the high prevalence might depend on how the feed was manufactured, such as whether there was a heat treatment step, but this detail was not provided. Some differences in prevalence might also be due to differences in sampling and testing methodology.

Prevalence of *Salmonella* in the feed mill environment is shown in Table 15 (Appendix A.3). The most commonly contaminated sample area was from the intake area. As discussed in Section 2.3, contamination was also found in dust as well as areas of the mill post-heat treatment, such as the cooler and storage bin, which has the potential to re-contaminate finished feed. *Salmonella* is more frequently isolated from dust samples than from feed ingredients or compound feed in the same mills, and contaminated dust tends to settle locally around implicated equipment; as such, sampling dust is informative for identifying contaminated areas such as equipment (Gosling et al. 2022).

Overseas data for serotypes that are prevalent in animal feed, ingredients and feed mills are provided in Table 14, Table 15 and Table 16 (Appendix A.3). While many different *Salmonella* serotypes may be detected in feed and feed ingredients, there is no doubt that certain serotypes are more frequently observed in feed. This is almost certainly due to these serotypes having superior tolerance to biotic stresses that may occur during feed processing (heat, desiccation, acid). For example, *S. Senftenberg* is a common serotype in feed, both in New Zealand and overseas; the heat and desiccation tolerance of this serotype is well documented (Davidson et al. 1966, Liu et al. 1969, Ng et al. 1969, Broennum Pedersen et al. 2008). Although there are some region-specific differences in serotype proportions, examples of serotypes that are commonly associated with feed overseas include *S. Mbandaka*, *S. Tennessee*, *S. Agona*, *S. Montevideo*, *S. Livingstone*, *S. Anatum*, *S. Rissen*, and *S. Kedougou*.

In Great Britain, the most common *Salmonella* serotypes reported from compound poultry feed were also commonly isolated from poultry, specifically in the broiler sector (Animal and Plant Health Agency 2020, 2021, 2022, Gosling et al. 2022). This linkage between *Salmonella* serotypes in feed and on-farm production is reported more frequently in poultry than in other food animal sectors, at least in part because of the routine environmental monitoring programmes in place to detect *Salmonella* in poultry flocks. A number of the serotypes with increased prevalence in broiler flocks are also associated with feed. In addition,

there has been an overall increase in *Salmonella* detections from chickens in 2021 over previous years. These increases may have been linked to the ban on using formaldehyde-based products in animal feed production since January 2018, across the EU and UK.

For red meat species, only isolates associated with animal clinical disease are identified in Great Britain. Of these, common feed-associated serotypes are often detected. For example, the second most common serotype (73 isolations) in cattle in 2021 was *S. Mbandaka* (Animal and Plant Health Agency 2022). This was a 16% increase compared with 2020 and approximately double the detections since 2018. The initial increase in detections may have been associated with feed contamination, but *S. Mbandaka* has now become resident on many dairy farms in Great Britain, with transmission between farms likely now occurring by other mechanisms. Another common feed-associated serotype in Great Britain, *S. Montevideo*, was the second most isolated serotype from sheep in 2021, which was a nine-fold increase in isolations compared with 2020 (3 isolations). However, *S. Montevideo* is also considered endemic in sheep in Great Britain.

*S. Enteritidis* was not identified as an important serotype associated with finished feed or the feed mills in any of the studies assessed. One study reported that some key *Salmonella* serotypes of public health importance (*S. Enteritidis*, together with *S. Infantis*, *S. Typhimurium* and its monophasic variant), accounted for only 5% of feed samples overall, and were mostly isolated from ingredient and non-production-environment samples, rather than production or finished product areas (Gosling et al. 2022). Feed had been considered as a possible route for the international spread of *S. Enteritidis* to poultry flocks because of the international trade of poultry feeds (Li et al. 2021). However, this was discounted in part because this serotype has not commonly been detected in poultry feed from the countries where the strain was detected in poultry, and feed was not imported to some of those countries. Instead, the spread was considered to be caused via international trade of infected breeding stocks.

Despite this downplaying the role of feed in the spread of *S. Enteritidis*, colonisation of chickens that were fed feed that had been experimentally inoculated with genetically tagged *S. Enteritidis* has been reported (Yang et al. 2017, Brooks et al. 2021). Thus, transmission of this serotype to poultry via the feed route could occur if feed was contaminated with this serotype.

# 4 EVALUATION OF ADVERSE HEALTH EFFECTS

## 4.1 *SALMONELLA* COLONISATION AND DISEASE IN FOOD-PRODUCING ANIMALS

### Key findings

- *Salmonella* intestinal colonisation of some animals such as pigs and poultry is typically asymptomatic, but colonisation in ruminant animals is more likely to result in disease.
- Concerns associated with *Salmonella* colonisation in food-producing animals arise from the potential for the *Salmonella* to be transmitted via food to humans and cause salmonellosis.

*Salmonella* intestinal colonisation in pigs and poultry is typically asymptomatic (with the exceptions for poultry discussed below, and for host-specific serotypes such as *S. Choleraesuis* for pigs (Allison et al. 1969, Uzzau et al. 2000, Jajere 2019)). However, colonisation in ruminant animals is more likely to result in clinical signs (European Food Safety Authority 2008). Within New Zealand, the ESR ERL receives *Salmonella* isolates from sick food-producing animals, which are predominantly from cows, then sheep (Table 10; Appendix A.2).

Poultry can be exposed to *Salmonella* from a range of sources, and intestinal colonisation for within-flock spread primarily occurs via the faecal-oral route. Although colonisation of poultry is usually asymptomatic, the serotypes *S. Pullorum* and *S. Gallinarum* cause serious infections for poultry (pullorum disease and fowl typhoid, respectively) (Thomson et al. 2008, Luo et al. 2021). However, these serotypes are not present in New Zealand (Egg Producers Federation of New Zealand 2002). Infection with other serotypes can lead to illness and death in chicks younger than two weeks old (Dunkley et al. 2009). Colonised broiler flocks present a risk for contamination of poultry meat. *Salmonella* from colonised chickens can also contaminate eggs, both externally (all serotypes) and in egg contents. *Salmonella*-contaminated eggs from breeder chickens pose a risk of colonisation of unhatched and newly hatched layer chicks, while contaminated eggs from layer chickens pose a risk to consumers. Contamination of egg contents can occur when *Salmonella* (most serotypes) penetrates through the eggshell into the contents, or through transovarian transmission when *Salmonella* (primarily, the invasive serotype *S. Enteritidis*) colonises the reproductive tract and migrates into egg contents before full egg formation. *S. Enteritidis* is the dominant serotype in European and North American layer flocks, and is the cause of the majority of human salmonellosis attributed to eggs in these regions. Certain phage types of *S. Enteritidis* such as DT8 have been reported to be capable of transovarian contamination of eggs, but the genetic determinants for what makes a strain capable of this are not well understood.

Salmonellosis can cause significant disease in cattle and is the most common disease associated with acute diarrhoea in adult dairy cows (Holschbach and Peek 2018). Depending on the serotype, it can also cause pneumonia, septicaemia and abortions, and can result in death if severe cases are left untreated. There are a number of *Salmonella* transmission pathways to cows; one of which is a contaminated feed supply. The risk of salmonellosis increases when magnesium supplementation, which is often added to cattle feed, is above recommended dose rates.

In sheep, salmonellosis often presents as outbreaks of abortion and deaths among ewes. New Zealand has seen recurring outbreaks with the serotype *S. Brandenburg*, which resulted in approximately 5% of ewes aborting (Clark et al. 2003, Clark et al. 2004, Baker et al. 2007). The outbreak strain was later found to be responsible for abortions in cattle, gastroenteritis in calves and adult cattle, as well as large numbers of human infections. The strain has also been detected in goats, deer and pigs, and has been isolated from animal feed.

Although salmonellosis can sometimes be a concern for animals, concerns associated with *Salmonella* colonisation in food-producing animals are usually with the potential for the *Salmonella* to be transmitted via food to humans and cause salmonellosis. This concern is reflected in the RMQ3 regarding the flow-on effect to humans from introduction of *Salmonella* into food-producing animals. Animal contact is another risk factor for human salmonellosis, but this Risk Profile focuses on foodborne transmission.

## 4.2 NEW ZEALAND HUMAN HEALTH SURVEILLANCE

### Key findings

- Salmonellosis is a self-limiting infection for most people, resolving without medical intervention. However, it can result in severe outcomes (including death) or long-term chronic conditions, particularly for the young, elderly, immunocompromised and those with underlying disease.
- There is no known safe level of exposure to *Salmonella*. The dose-response is influenced by factors such as the *Salmonella* serotype, and food type.
- The yearly incidence of salmonellosis in New Zealand was lower for the period covered in this report (2011 to 2022; 13.9 to 25.6 cases per 100,000 population) compared with the period covered in the 2011 Risk Profile (2003 to 2010; 26.2 to 37.5 cases per 100,000 population). However, fewer notifications during 2020 and 2021 could be attributed to the impact of the public health response to the COVID-19 pandemic.
- One death associated with salmonellosis occurred during the reporting period (in 2017).
- Hospitalisation rates varied yearly from 11.8% to 30.4% of all salmonellosis cases, and were the highest in 2021 and 2022. The number of hospital admissions were not higher in these years, but the numbers of hospitalisations did not show the same COVID-19 response-specific reduction as the number of notifications, which affected the rates.
- *S. Typhimurium* was the most frequently isolated serotype from human salmonellosis cases in New Zealand, followed by *S. Enteritidis* (39.3% and 11.8%, respectively, for the period 2011 to 2022).
- The reported number of salmonellosis outbreaks each year was similar between the periods 2005 to 2010 (8 to 26) and 2011 to 2022 (5 to 27). There have been no reported human outbreaks of salmonellosis identified over the 2011 to 2022 period that were linked to transmission through the food chain arising from contaminated livestock feed.
- Antimicrobial resistance among non-typhoidal *Salmonella* isolated from human, animal and environmental samples in New Zealand remains relatively low. In 2019, 91.0% of tested isolates were fully susceptible to all 11 antimicrobials (89.3% of human isolates and 93.1% of non-human isolates). Rates were similar to the 92% fully susceptible isolates reported in 2010.

#### 4.2.1 Salmonellosis in New Zealand

Information on salmonellosis disease characteristics, dose-response and New Zealand laboratory testing are provided in Appendix B.

Salmonellosis is a notifiable disease in New Zealand. The annual notification rate of salmonellosis was quite stable from 2011 and 2019, ranging between 21.2 and 25.6 cases of salmonellosis per 100,000 population (Table 5). Notifications were much lower in 2020 (708 cases; 13.9 cases per 100,000 population), 2021 (714 cases; 13.9 cases per 100,000 population), and 2022 (750 cases; 14.6 cases per 100,000 population). This could be attributed to the impact of the COVID-19 pandemic public health response. Public health and social measures to prevent the spread of COVID-19 in New Zealand were introduced in March 2020 and remained in place throughout 2021, with all restrictions ending on 13 September 2022.<sup>54</sup> However, the degree of stringency of measures differed over this time period. The multiple aspects of the response listed below make it difficult to attribute any changes to notification rates to specific COVID-19 related factors or to true changes in disease incidence.

- Changes in testing priorities of laboratories, with resources diverted to the COVID-19 response.
- More emphasis on personal hygiene; for example, hand sanitiser use.
- Travel restrictions within New Zealand and overseas.
- Physical distancing requirements and limits on hospitality businesses leading to less socialising and private functions.
- Changes in the food supply; supermarkets, corner stores/dairies and convenience stores were the main food retailers open during lockdown periods; restaurants, cafes and takeaway shops were closed or had limited functionality depending on the level of lockdown and often were modified to be contactless, possibly resulting in more home cooking and more takeaway food consumption.
- Behavioural changes such as fewer visits to healthcare providers.

Hospitalisation and fatality rates for notified cases of salmonellosis in New Zealand are shown for the years 2011 to 2022 in Table 5, and for 2008 to 2022 in Figure 3. These outcomes are not always reported for each notified case, so these percentages expressed in terms of the total number of case notifications may differ slightly from the true percentages (see Table 5 footnotes b and c). The number of hospital admissions with salmonellosis as a primary or secondary diagnosis varied slightly year by year, with the lowest number of hospitalisations in 2014 (113; 11.8% of notifications) and highest in 2019 (230 hospitalisations; 19.4% of notifications). The high percentages of hospitalisations from 2020 to 2022 reflect the smaller number of notified cases during these years while the numbers hospitalised did not change to the same extent. At least for 2020, this may have been a consequence of only the most severe salmonellosis cases seeking healthcare at a time when there were concerns about healthcare capacity and COVID-19 spread (Imlach et al. 2021).

Deaths associated with salmonellosis are rare. There was one fatality per year associated with salmonellosis from 2005 to 2009, and no fatalities during the period 2010 to 2014. There was a single death for the time period 2011 to 2022, which occurred in 2017.

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<sup>54</sup> <https://covid19.govt.nz/current-phase-of-our-covid-19-response/>; accessed 20 June 2023

**Table 5. Notifications, hospitalisations and deaths due to salmonellosis in New Zealand from 2011 to 2022.**

Year	Number of cases <sup>1</sup>	Incidence (cases/100,000)	Hospitalisation of cases (% of notifications) <sup>2</sup>	Number of cases who died (% of notifications) <sup>3</sup>	References
2011	1056	24.0	135 (12.8)	0 (0.0)	(Lim et al. 2012)
2012	1085	24.5	174 (16.0)	0 (0.0)	(Lopez et al. 2013)
2013	1143	25.6	146 (12.8)	0 (0.0)	(Horn et al. 2014)
2014	954	21.2	113 (11.8)	0 (0.0)	(Horn et al. 2015)
2015	1051	22.9	172 (16.4)	0 (0.0)	(Lopez et al. 2016)
2016	1091	23.2	207 (19.0)	0 (0.0)	(Pattis et al. 2017)
2017	1119	23.3	214 (19.1)	1 (0.1)	(Pattis et al. 2019b)
2018	1100	22.5	227 (20.6)	0 (0.0)	(Pattis et al. 2019a)
2019	1188	24.2	230 (19.4)	0 (0.0)	(Pattis et al. 2020)
2020 <sup>4</sup>	708	13.9	165 (23.3)	0 (0.0)	(Horn et al. 2021)
2021 <sup>4</sup>	714	13.9	217 (30.4)	0 (0.0)	(Pattis et al. 2022)
2022	750	14.6	212 (28.3)	0 (0.0)	(Horn et al. 2023)

<sup>1</sup> Notifications recorded in EpiSurv

<sup>2</sup> Hospital discharges recorded in the National Minimum Data Set (NMDS) with ICD-10 code A02.0 (*Salmonella* enteritis) reported as primary or any other diagnosis code. The percentage is the number of NMDS hospitalisations as a percentage of the number of EpiSurv notifications. Cases hospitalised may not be notified on EpiSurv. Therefore, percentages are indicative only since hospitalisation and notification data sources differ. See references for details of data sources.

<sup>3</sup> Deaths are based on information reported in EpiSurv

<sup>4</sup> The lower-case numbers can be attributed to the impact of the COVID-19 public health response.



**Figure 3. Salmonellosis EpiSurv notifications (line) and Ministry of Health National Minimum Dataset hospitalisations (bar) by year, 2008–2022. Graph reproduced from Horn et al. (2023).**

The incidence of salmonellosis is characterised by a late summer peak and a winter trough. Historically, notification rates have been variable across New Zealand, but the highest rates are often reported from the lower half of the South Island. In 2022, the highest rates were from South Canterbury (27/100,000), Wairarapa (26/100,000), the lower South Island (22/100,000), and Canterbury (21/100,000) (Horn et al. 2023).

In 2022, salmonellosis notification rates were lower for people residing in urban areas (8-14/100,000 population) compared with 'rural settlement' areas (20 per 100,000) and 'rural other' areas (23/100,000).

During 2022, the reported notification and hospitalisation rates were higher for females (397 cases, 15.4 cases per 100,000 population; 4.3 hospital admissions per 100,000 population) than males (13.8 cases per 100,000 population, 352 cases; 3.9 hospital admissions per 100,000 population) in 2022. However overall, there is little difference between males and females for these measures.

Age-specific notification and hospitalisation rates of salmonellosis are consistently highest for the 0 to 4 year age group (83.3 cases per 100,000 population, and 23.3 hospital admissions per 100,000 population in 2022).

#### 4.2.2 Serotypes causing disease in New Zealand

The ESR ERL performs typing of *Salmonella* for the whole of New Zealand.

Table 6 displays the peak years and total number of cases for serotypes that have caused 50 or more salmonellosis cases between 2011 and 2022. There were 12,349 New Zealand cases of salmonellosis reported for the period 2011 to 2022 for which the *Salmonella* serotype was available<sup>55</sup>. *S. Typhimurium* was the reported cause of 39.3% of these cases and the next most frequently reported serotype was *S. Enteritidis* (11.8% of cases). When considering serotype and phage type, *S. Typhimurium* DT56 variant was the most frequently reported phage type (5.8% of the cases for the years 2011 to 2019; from 1 November 2019, phage typing was discontinued). Following implementation of sequence typing, the most commonly reported ST was *S. Typhimurium* ST19 (554 cases, 16.9% of cases from 2019 to 2022).

As discussed in Section 3.1, all of the listed *Salmonella* serotypes identified from New Zealand livestock feed have also been isolated from human cases of salmonellosis in New Zealand. Furthermore, five of the most common feed serotypes (*S. Typhimurium*, *S. Brandenburg*, *S. Infantis*, *S. Agona* and *S. Montevideo*) are amongst those that have caused 50 or more cases during the period 2011 to 2022 (Table 6).

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<sup>55</sup> Numbers are from yearly reports ([https://surv.esr.cri.nz/enteric\\_reference/human\\_salmonella.php](https://surv.esr.cri.nz/enteric_reference/human_salmonella.php)). For some years, these numbers differ slightly those reported in the annual foodborne outbreak reports (<https://www.mpi.govt.nz/science/food-safety-and-suitability-research/human-health-surveillance-and-attribution-programme/foodborne-disease-annual-reports/>).

**Table 6. *Salmonella* serotypes and phage types that caused 50 or more cases during the period 2011 to 2022 – peak occurrence and total cases.<sup>1</sup>**

Serotype / phage type (DT)/ sequence type (ST) <sup>2</sup>	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total isolates 2011-2022
<b>Total typed</b>	<b>1,095</b>	<b>1,106</b>	<b>1,216</b>	<b>1,022</b>	<b>1,133</b>	<b>1,150</b>	<b>1,217</b>	<b>1,125</b>	<b>1,153</b>	<b>726</b>	<b>668</b>	<b>738</b>	<b>12,349</b>
<b>Typhimurium (total)</b>	<b>495</b>	<b>459</b>	<b>481</b>	<b>392</b>	<b>447</b>	<b>387</b>	<b>432</b>	<b>346</b>	<b>412</b>	<b>334</b>	<b>314</b>	<b>349</b>	<b>4,848</b>
DT56 variant <sup>4</sup>	-	-	122	72	96	64	117	70	49	-	-	-	590
DT101	50	26	26	41	56	47	66	60	36	-	-	-	408
DT135	46	44	48	35	64	30	34	39	21	-	-	-	361
RDNC <sup>5</sup>	28	26	33	36	19	42	44	27	26	-	-	-	281
DT1	54	35	30	22	38	34	22	16	7	-	-	-	258
DT160	66	58	69	27	9	6	5	7	4	-	-	-	251
DT9	24	11	13	17	27	42	14	21	13	-	-	-	182
DT108/170	3	17	9	12	11	22	13	4	83	-	-	-	174
DT42	14	19	20	18	24	12	27	13	11	-	-	-	158
DT156	29	21	17	9	27	12	4	12	1	-	-	-	132
DT12a	28	26	15	20	18	6	7	7	0	-	-	-	127
DT23	9	20	8	13	10	8	6	16	17	-	-	-	107
DT193	4	10	10	17	9	4	10	3	7	-	-	-	74
ST19	-	-	-	-	-	-	-	-	36	167	149	202	554
ST568	-	-	-	-	-	-	-	-	26	95	94	98	313
ST2297	-	-	-	-	-	-	-	-	13	68	44	28	153
Monophasic ST34 <sup>5</sup>	-	-	-	-	-	-	-	-	6	17	21	11	55
<b>Enteritidis (total)</b>	<b>134</b>	<b>125</b>	<b>137</b>	<b>116</b>	<b>110</b>	<b>114</b>	<b>150</b>	<b>130</b>	<b>167</b>	<b>72</b>	<b>129</b>	<b>79</b>	<b>1,463</b>
DT11	2	52	27	39	45	46	55	30	31	-	-	-	327
RDNC <sup>5</sup>	17	13	7	31	20	20	16	15	11	-	-	-	150
DT1	10	6	19	14	17	9	7	9	8	-	-	-	99
DT1b	8	9	14	5	4	8	7	14	4	-	-	-	73
DT21	5	8	7	3	1	4	13	8	12	-	-	-	61
DT6a	7	8	8	7	3	3	9	10	5	-	-	-	60
DT9a	56	0	1	0	0	0	0	0	0	-	-	-	57
DT26	2	3	9	4	0	1	7	6	21	-	-	-	53
ST11	-	-	-	-	-	-	-	-	22	50	59	39	170
ST183	-	-	-	-	-	-	-	-	1	20	65	39	125
Brandenburg	34	34	52	35	52	67	55	45	42	38	37	21	512
Bovismorbificans	3	8	8	4	23	39	52	83	50	58	49	46	423
Infantis	65	52	70	56	52	14	19	16	26	8	8	7	393
Saintpaul	31	27	43	26	37	35	27	39	22	26	31	22	366
Stanley	28	22	31	34	25	60	39	35	41	12	9	18	354
Subsp. (I) ser. 4,[5],12:i:- <sup>5</sup>	21	36	27	22	22	23	28	26	48	0	0	0	253
Weltevreden*	16	24	28	31	18	18	21	21	20	11	2	6	216
Mississippi	13	12	20	21	16	21	15	15	15	15	10	15	188
Paratyphi B var Java	5	7	11	13	21	18	26	32	27	11	3	3	177
Agona	20	11	11	15	12	18	16	27	14	4	4	10	162
Thompson	7	2	16	5	32	13	12	10	9	15	11	13	145
Newport	8	9	7	10	14	22	20	10	9	4	1	2	116

Serotype / phage type (DT)/ sequence type (ST) <sup>2</sup>	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total isolates 2011-2022
Virchow	18	17	15	5	16	10	7	7	8	4	0	9	116
Subsp. (I) ser. 4,[5],12:b:-	11	5	14	6	6	8	10	15	8	0	0	0	83
Javiana	3	4	9	11	5	11	18	6	5	1	2	8	83
Kentucky	4	10	6	8	11	10	15	8	9	0	1	0	82
Oslo	4	8	7	8	7	7	10	8	7	1	1	3	71
Pensacola	2	5	6	6	3	7	5	9	5	3	7	7	65
Corvalis	10	8	9	6	4	11	4	5	3	0	0	1	61
Bareilly	8	4	1	5	3	9	8	8	7	2	1	5	61
Montevideo	1	26	11	7	3	2	2	5	2	0	0	1	60
Hvittingfoss	1	4	4	3	9	6	3	5	5	2	6	2	50

<sup>1</sup> Data are from reports available from yearly reports (<https://www.esr.cri.nz/our-research/nga-kete/infectious-disease-intelligence/enteric-reference-testing/human-salmonella-isolates/>; accessed 4 October 2023).

<sup>2</sup> From 1st November 2019, ESR replaced phage typing (DT) of *S. Typhimurium* and *S. Enteritidis* with WGS which returns a ST. The ST does not relate to DT.

<sup>3</sup> *S. Enteritidis* RDNC and *S. Typhimurium* RDNC are not single serotypes, but a grouping of serotypes. RDNC stands for 'reaction does not conform' and indicates that the isolate does not match any recognised serotypes.

<sup>4</sup> *S. Weltevreden* also includes and var. 15+.

<sup>5</sup> Following the introduction of WGS, *Salmonella* subsp. (I) ser. 4,5,12:i:- is now reported as monophasic *S. Typhimurium*, which may include several STs, for example monophasic ST34.

### 4.2.3 Antimicrobial resistance of New Zealand *Salmonella* strains

Hospital and community laboratories are requested to refer all *Salmonella* isolates from human salmonellosis cases to ESR as part of the laboratory-based surveillance.<sup>56</sup> *Salmonella* from other sources, including food, animal and environmental sources, are also referred to ESR for epidemiological typing. The ESR Antibiotic Reference Laboratory also tests the antimicrobial susceptibility all isolates of phage types that were internationally recognised as being multidrug-resistant. The antimicrobial susceptibility of a representative sample (approximately 20%; every fifth isolate received) of non-typhoidal isolates was tested yearly until 2016, and again in 2019.

Results for antimicrobial resistance testing for the years 2010 to 2019 are compiled in Appendix B.4. The most recent report states that resistance remains relatively low, with 91.0% of *Salmonella* isolates tested fully susceptible to all 11 antimicrobials (89.3% of human isolates and 93.1% of non-human isolates) (ESR 2019). This is similar to data from 2010 where 92.0% of isolates remained fully susceptible; the range in susceptibility from 2010 to 2019 was 85.5% to 92.0%. Note that the panel of antimicrobials tested differed slightly across years; for example, susceptibility was tested to 13 antibiotics in 2010, and to 12 antibiotics in 2019, and nine of the antibiotics were the same for both years.

For the time period 2015 to 2019, *Salmonella* isolates from salmonellosis cases reported to have travelled overseas were significantly ( $p < 0.05$ ) more resistant to at least one antimicrobial than isolates from cases for whom no recent overseas travel was reported.

Animal feed safety has been recognised as an important component of a sustained One Health response to antimicrobial resistance.<sup>57</sup> Antimicrobials have been used in animal feed

<sup>56</sup> <https://surv.esr.cri.nz/antimicrobial/salmonella.php>; accessed 2 November 2022

<sup>57</sup> <https://apps.who.int/iris/bitstream/handle/10665/337525/WHO-EURO-2020-1631-41382-56388-eng.pdf>; accessed 15 June 2023

for about 70 years to treat diseases, as well as to boost growth, improve feed utilisation and reduce mortality; that is, to obtain an improvement in productivity.<sup>58</sup> Antibiotic growth promoters include any medicine that inactivates or inhibits bacteria, and are administered at a low, sub-therapeutic dose to improve productivity rather than for treating disease. The use of antibiotic growth-promoters has been banned in EU countries since 1 January 2006, as well as in many other countries, and they are not approved for use in New Zealand.

No data were found on antimicrobial resistance of New Zealand *Salmonella* isolates specifically from livestock feed because this level of detail is not provided in ESR reporting. Various studies have investigated the antimicrobial resistance of *Salmonella* from animal feed, feed components and feed mill environments from other countries (Appendix A.3). Resistance was most commonly reported toward the antibiotics amikacin, tetracycline, streptomycin, cefotaxime and sulfisoxazole (Parker et al. 2022a). The proportion of antimicrobial resistant isolates differed by geographic location. Another study found that there was a higher probability was higher for detecting antimicrobial resistant isolates from the Australian feed mill equipment compared with finished feed ( $p < 0.001$ ) and raw ingredients ( $p = 0.006$ ) (Parker et al. 2022b).

#### 4.2.4 Reported New Zealand outbreaks

The number of reported outbreaks and case numbers of salmonellosis, are shown in Table 7. Over the period 2011 to 2022, the annual number of salmonellosis outbreaks with food reported as a possible mode of transmission ranged from two (2020 and 2022) to 15 (2019). The total number of cases associated with the outbreaks over the same period ranged between 13 (2022) and 186 (2019).

**Table 7. Reported salmonellosis outbreaks in New Zealand and information on those reported as foodborne (2011-2022).**

Year	Salmonellosis outbreaks	Cases associated with salmonellosis outbreaks	Salmonellosis outbreaks reported as foodborne (number of cases) <sup>1</sup>	Reference
2011	15	77	8 (42)	(Lim et al. 2012)
2012	27	149	11 (100)	(Lopez et al. 2013)
2013	18	98	9 (45)	(Horn et al. 2014)
2014	23	116	7 (44)	(Horn et al. 2015)
2015	18	101	3 (30)	(Lopez et al. 2016)
2016	24	130	12 (78)	(Pattis et al. 2017)
2017	13	40	4 (15)	(Pattis et al. 2019b)
2018	14	75	5 (17)	(Pattis et al. 2019a)
2019	27	226	15 (186)	(Pattis et al. 2020)
2020	8	34	2 (12)	(Horn et al. 2021)
2021	8	99	5 (90)	(Pattis et al. 2022)
2022	5	44	2 (13)	(Horn et al. 2023)
<b>Total</b>	<b>200</b>	<b>1,145</b>	<b>83 (672)</b>	

<sup>1</sup> An outbreak is classed as foodborne if food was recorded as one of the likely modes of transmission applicable to the outbreak. Single outbreaks may have multiple pathogens, modes of transmission, settings where the exposure occurred, or settings where preparation of food was conducted. Other modes of transmission may also be reported.

<sup>58</sup> <https://www.fao.org/antimicrobial-resistance/key-sectors/animal-feeding/en/>; accessed 15 June 2023

#### **4.2.5 Animal feed-associated outbreaks of human salmonellosis in New Zealand**

For the years 2011 to 2022, there were no reports of human salmonellosis outbreaks that were linked to transmission through the food chain, arising from feed for food-producing animals. However, there were 19 outbreaks where at least one product from animals considered in this report were a suspected source; these included eggs, poultry meat, ham/pork, beef or and meat where the type was not specified (for example, spit roast or minced meat). For most of those reports, the evidence for the food was not strong. Outbreaks with strong evidence include those with a statistically significant elevated risk ratio or odds ratio (95% confidence) from an epidemiological investigation and/or laboratory evidence with the same organism and strain detected in both disease cases and vehicle (to the highest available level of identification) (Horn et al. 2023).

The 2011 Risk Profile (Cressey et al. 2011) described an incident in 2003 whereby contamination of broiler poultry feed with *S. Typhimurium* DT1 was detected through industry testing, which was thought to arise from the wheat used in the feed formulation (Wong 2003). There was a concomitant increase in the same phage type detected from chicken at retail, and human salmonellosis cases.

#### **4.2.6 2021 *S. Enteritidis* DT8, ST11 outbreak (SE 2021) associated with poultry meat and eggs**

This section provides an overview of the recent poultry-associated *S. Enteritidis* outbreak (SE 2021). Although there was no evidence that the outbreak was caused by contaminated poultry feed, an assessment of the outbreak, and subsequent risk management practices in response to the outbreak, is important for considering how the outbreak has changed the risk of contamination of animal feed, pertinent to RMQ2.

On 25 February 2021, ESR serotyped an isolate from a raw broiler chicken carcass, sampled on 17 February 2021 during routine NMD programme testing from a large-scale poultry meat processor, as *S. Enteritidis* (Jackie Wright, ESR, pers. comm). The isolate was entered into the NMD database on 3 March 2021. This represented the first detection of this serotype from New Zealand poultry. On 19 March 2021, MPI was informed that following WGS, the ST11 isolate formed a close genomic cluster (<5 SNPs) with an ongoing cluster of human cases from multiple Public Health Units from the North Island, predominantly the Auckland region, that dated back to 2019 (Ministry for Primary Industries 2021a, Pattis et al. 2022). The outbreak strain (designated as *S. Enteritidis* genomic cluster profile *S. Enteritidis\_2019\_C\_01*) was subsequently identified at additional poultry operations, one of which was a major supplier of day-old chicks and hatching eggs for the poultry meat and egg industries in New Zealand, and the other a rearer of pullets for egg-laying (Ministry for Primary Industries 2021a). Both the initial broiler and rearer detections were from farms supplied by the hatchery on the same day (19 January 2021). The working assumption was that the hatchery was the source of colonisation in downstream operations and therefore further colonisations within connected poultry producers (egg laying, broiler, or rearer) were likely.

As of 30 May 2023, there have been 128 confirmed outbreak cases (person notified in New Zealand with the *S. Enteritidis* genomic cluster profile *S. Enteritidis\_2019\_C\_01*), as well as an additional six cases that were epidemiologically linked; totalling 134 cases. The earliest case was from May 2019, and at the time that this document was produced, the report date of the most recent case was 3 February 2023. The proportion of cases hospitalised with the outbreak strain was 36.6% (49/134 cases) (EpiSurv data; Shevaun Paine, pers. comm, 9 May 2023). The hospitalisation rate was higher than for all salmonellosis cases (792/2889 cases;

27.4%) or total *S. Enteritidis* cases (112/397 cases; 28.2%) over a similar reporting period. The outbreak was not considered to have materially affected the total number of salmonellosis cases reported for 2021 (Pattis et al. 2022).

Most of the isolates comprising the outbreak strain from cases and the poultry environment were phage typed as DT8. Isolates from some cases were originally typed as DT28, but later retyped as DT8 during the outbreak response. DT28 reacts with the same phages as DT8 but the reaction intensity with phages 3, 7 and 11 are much weaker (Jackie Wright, ESR; pers. comm; 16 July 2021). Phage types DT2 and DT23 were also identified amongst genomically linked poultry isolates. Isolates of DT8 and DT28 have been reported to be potentially capable of transovarian contamination of eggs in international studies (Thiagarajan et al. 1994, Thiagarajan et al. 1996, Dawoud et al. 2011), and DT8 was previously reported to be the predominant phage type of *S. Enteritidis* from both human outbreaks and poultry flocks in the US (Altekruse et al. 1993, Denagamage et al. 2016). In addition, all isolates were ST11 which is the most common sequence type of *S. Enteritidis* internationally (Luo et al. 2021), and which has been implicated in large outbreaks associated with both eggs and poultry meat internationally (European Centre for Disease Prevention and Control and European Food Safety Authority 2021, 2022).

Multiple lines of evidence supported that poultry meat and/or eggs were the most likely source of the outbreak (Jefferies et al. 2021, Ministry for Primary Industries 2021a, French et al. 2022, Pattis et al. 2022). These included:

- There was a very high degree of similarity between all SE\_2019\_C\_01 isolates from poultry and clinical sources (<5 SNP differences). This is consistent with transmission between poultry and humans, most likely through the food chain.
- The epidemiology of human salmonellosis cases infected with SE\_2019\_C\_01 detected in New Zealand from 2019-2021 is consistent with a foodborne outbreak associated with multiple contaminated poultry and/or egg exposure pathways with amplification events which themselves can be (and have been) defined as outbreaks.
- Of the SE 2019\_C\_01 cases that presented late 2021 to early 2022 that were interviewed by a Public Health Unit-administered supplementary questionnaire, the majority (10/11) reported having some exposure to poultry meat and/or eggs during their incubation period for disease. The remaining case possibly had exposure through home-made mayonnaise; however, recall bias was a factor in the case interview. As consumption of poultry meat and eggs are common in the general population, it is difficult to interpret this finding in isolation. One case was a maintenance worker at the hatchery from which the *S. Enteritidis* outbreak strain was detected, who possibly had contact with chicken faeces on the shed floor where chickens lay eggs. The small case numbers and limitations in collecting dietary histories, including biases and resourcing required to implement a detailed dietary questionnaire, have prevented further epidemiological analysis. The timelines of case detection also limits the acquisition of food products consumed by cases for testing. However, the food histories of recent cases do continue to identify poultry and/or eggs as plausible sources of ongoing exposure to this pathogen.
- There was an increase in human cases concomitant with poultry meat from the flock that tested positive during NMD programme testing being released onto the market for consumption.
- The outbreak strain was detected in samples taken in 2020 and 2021 from the layer farm that supplied eggs to a restaurant involved in a 2019 outbreak associated with a raw egg dessert.

- The majority of isolates of the outbreak strain were DT8, which might contaminate the yolk of eggs through transovarian transmission, and therefore increase the risk to human health through consumption of uncooked or undercooked egg yolks. Overseas experience shows that *S. Enteritidis* typed as DT8 or ST11 can cause substantial outbreaks of human salmonellosis associated with poultry meat and or eggs.

Following the notification of *S. Enteritidis* detection in poultry on 19 March 2021, MPI launched response and regulatory activities (Ministry for Primary Industries 2021a) which included:

- A historical/traceback phase to investigate earlier detections of the outbreak strain (covering the period May 2019 to 19 March 2021);
- An investigative phase to determine the scope of the outbreak (19 March to 22 April 2021);
- A delimiting phase to understand the prevalence and risks associated with the outbreak strain across commercial layer flocks (22 July 2021 to 10 September 2021);
- An emergency control scheme (ECS) to temporarily regulate the poultry production supply chain and manage risks to public health and international trade of *S. Enteritidis*, which came into effect on 6 October 2021.
- Targeted consultation with the poultry industry on proposed regulatory options for long term management of *S. Enteritidis* in early 2022, with a recommendation to the Minister for Food Safety for poultry producers to operate under a Risk Management Programme (RMP).
- Long term regulations which came into force 6 October 2022, requiring poultry producers to operate under an RMP no later than 1 November 2023. Implemented management programmes are covered in Section 5.1.

#### 4.2.7 Case control studies concerning *Salmonella* and animal feed in New Zealand

As animal feed is not directly consumed by humans, epidemiological evidence for a role of animal feed in human disease is rare.

A case-control study was conducted following an outbreak involving *S. Typhimurium* DT42 from 67 South Island cases that had been notified from 13 October 2008 to 28 January 2009 (McCallum et al. 2013). The same serotype was isolated two weeks earlier from poultry feed raw materials (broll, which contains wheat flour and grain particles), leading to the initial hypothesis that consumption of chicken or egg products may have been associated with *S. Typhimurium* DT42 infection. Compared with the controls, the cases had 4.5 times the odds of eating uncooked baking mixture than controls (adjusted for age, sex, and Public Health Unit, 95% confidence interval [CI] 1.6-12.5, *p*-value 0.001). Of the individual baking ingredients, flour had an odds ratio (OR) of 5.7 (95% CI 1.1-29.1, *p*-value 0.035). Cases and controls were also asked a range of questions regarding chicken and egg consumption, none of which came close to significance (adjusted ORs of 0.5-2.2, *p*-values 0.31–0.93). The outbreak strain was subsequently isolated from both flour from cases' houses, and unopened batches at retail and recalled product. Therefore, rather than the poultry feed contributing to the outbreak, it was found that the broll came from the same feed mill that processed product for human consumption.

In 2011 an increase in confirmed salmonellosis in dairy herds was reported and in 2011-2012 a case-control study was conducted to identify herd-level risk factors (Stevenson et al. 2016). In a multivariable analysis, use of continuous feed troughs (adjusted odds ratio (aOR) 6.2, 95% CI: 2.0–20), use of pelletised magnesium supplements (aOR 10, 95% CI 3.3–33) and use of palm kernel meal as a supplementary feed (aOR 8.7, 95% CI 2.5–30) were positively associated with a herd-level outbreak of salmonellosis during the study period. Magnesium

supplementation raises the rumen pH and may improve survival of *Salmonella* during passage through the rumen. The authors of this study speculated that the positive association with palm kernel meal may have been due to the meal as a vehicle for *Salmonella* introduction or due to the meal as an indicator of intensively managed herds.

#### 4.2.8 New Zealand source attribution studies

From an expert elicitation carried out in 2013, the estimated proportion of human salmonellosis in New Zealand that is due to foodborne transmission was 62.1% (95th percentile credible interval 35.2-86.4%, based on self-assessed performance weighting) (Cressey et al. 2019).

A 2013 New Zealand-wide study combined phenotypic (serotype and phage type) and genotypic (PFGE and Multilocus variable-number tandem repeat analysis (MLVA)) data from *Salmonella* isolates, with source attribution modelling, to identify sources or reservoirs responsible for human salmonellosis (French et al. 2013). A total of 956 *Salmonella* isolates were collected and typed from both human clinical cases and potential animal reservoirs over a 12-month period. Findings indicated that cattle were associated with the majority (60%; 30-86%) of all *Salmonella* infections, with most being *S. Typhimurium*. Poultry and wild birds were assigned as the source of 16% (1-44%) and 15% (0-42%) of salmonellosis cases respectively. Other sources such as sheep and pigs were estimated to account for fewer than 10% of cases. One limitation of the assignment of cases to poultry is that specific information was not always available for the source of the poultry isolates and the reason for sampling (although poultry feed isolates were excluded); as such, the representativeness of this dataset was uncertain.

No recent New Zealand source attribution studies considered animal feed. A 2010 report sought to quantify the proportion of foodborne human salmonellosis cases attributable to the following pathways: animal feeds, specific foods, and domestically produced versus imported foods (Adlam et al. 2010). In relation to the animal feed component, the study referenced the 2011 Risk Profile (Cressey et al. 2011) stating that animal feed was not considered a significant source of human salmonellosis in New Zealand, although the available information on the *Salmonella* status of feed and feed ingredients in New Zealand was not sufficiently comprehensive to exclude animal feed as a source of human salmonellosis cases.

### 4.3 SALMONELLOSIS IN OTHER COUNTRIES

#### Key findings

- New Zealand notified salmonellosis rates for 2018 to 2021 (13.9 to 24.3 cases per 100,000 population) were similar to rates from the EU (13.7 to 20.1 cases per 100,000 population), and lower than Australian rates (41.7 to 57.5 cases per 100,000 population). Rates were higher than reported in the US for 2018 and 2019 (18.3 and 17.1 cases per 100,000 population), but similar during 2021 and 2022 (13.3 and 14.2 cases per 100,000 population) where the COVID-19 response affected reporting levels in both countries.
- Certain serotypes from international surveillance data that are frequently isolated from animal feed are among those also commonly isolated from food-producing animals, particularly from poultry. While this type of evidence is primarily circumstantial, investigations have also been carried out that link *Salmonella* contamination of animal feed to subsequent *Salmonella* colonisation of poultry, pigs and cattle.
- Some salmonellosis outbreaks have been reported where cases consumed poultry meat, eggs or pork, and traceback efforts identified a linkage with animal feed contaminated by

the outbreak strain. Outbreaks may go undetected, particularly if the serotypes are already common in the human population, or in the absence of investigations conducting genetic linkages between animal feed, food and human cases.

#### 4.3.1 Incidence of salmonellosis in other countries compared with New Zealand

The incidence of notified cases of salmonellosis in New Zealand for the years 2018 to 2021 is similar to rates in other developed countries and regions, particularly for the EU (13.7 to 20.1 cases per 100,000 population) (Table 20, Appendix B.5). Annual rates of salmonellosis for these years in Australia (41.7 to 57.5 cases per 100,000 population) were higher than New Zealand rates. As was reported for New Zealand, the annual incidence of salmonellosis was lower during 2020 and 2021 relative to 2019 for all regions for which data were reported in Table 20, due to the impact of the COVID-19 pandemic. In 2018 and 2019, New Zealand rates of salmonellosis were slightly higher than in the US. Specifically, there were 22.5 and 24.3 cases per 100,000 population in New Zealand compared with 18.3 and 17.1 cases per 100,000 population in the US, for 2018 and 2019, respectively. However, there was a bigger reduction in salmonellosis incidence in New Zealand due to COVID-19 than was observed in the US. This resulted in more similar rates between New Zealand and the US in 2020 and 2021 (13.9 cases per 100,000 population in New Zealand for both years compared with 13.3 and 14.2 cases per 100,000 population in the US for 2020 and 2021, respectively).

The proportions of *Salmonella* serotypes observed from cases varies considerably based on country. As has been seen yearly in New Zealand, the most common serotype from cases in Australia was *S. Typhimurium*. In contrast to New Zealand, the dominant serotype in the EU, US and Canada was *S. Enteritidis*.

#### 4.3.2 Health burden of infection with *Salmonella* in New Zealand and internationally

The most recent update of the estimate of the burden of foodborne disease for New Zealand, which is based on surveillance data for 2013, includes an estimate for foodborne salmonellosis of 74 disability adjusted life years (DALYs)<sup>59</sup> (Cressey and Lake 2014). This placed foodborne salmonellosis fifth on the list for foodborne disease burden (after norovirus infection, campylobacteriosis, listeriosis and STEC infection). The New Zealand estimate of the burden of foodborne disease from salmonellosis does not subdivide the burden according to specific foods. The estimate does not include a monetisation of the burden of disease.

An expert elicitation study conducted by the World Health Organization (WHO) Foodborne Disease Burden Epidemiology Reference Group Source Attribution Task Force has also estimated the relative contribution of food to the global burden of non-typhoidal salmonellosis and other predominantly foodborne pathogens. The foodborne transmission route was considered more important in the developed subregions (America, Europe and the Western Pacific) compared with developing subregions (African, American and Eastern Mediterranean region). In the developing subregions, there were relatively more contributions from other routes animal contact, water and soil). For the Western Pacific region (that included New Zealand), the proportion of salmonellosis acquired through foodborne transmission was estimated at 0.74 (95% uncertainty interval 0.45-0.93) (Hald et al. 2016).

The Global Burden of Diseases, Injuries, and Risk Factors Study 2017 estimated that *Salmonella* enterocolitis resulted in 95.1 million cases (95% uncertainty interval: 41.6-184.8), 50,771 deaths (2824-129,736), and 3.10 million DALYs (95% uncertainty interval: 0.39-7.39)

<sup>59</sup> The calculation for DALYs is the number of years of life lost to mortality combined with the number of years lived with disability.

in 2017. Furthermore, the global burden of invasive salmonellosis for 2017 has been estimated to be 4,263,500 DALYs (95% uncertainty interval: 2,384,900 to 7,382,000), or a rate of 616,800 (95% uncertainty interval: 347,300 to 1,076,200) per million people (Stanaway et al. 2019). The DALY rates in the Southeast Asia, east Asia and Oceania super-region were calculated at 49,900 (95% uncertainty interval: 27,400-87,600) per million people. The highest rate of invasive salmonellosis was in sub-Saharan Africa with 2,687,700 (95% uncertainty interval: 1,495,400-4,552,800) DALYs per million people.

A 2017 Belgian study estimated and forecasted the burden of salmonellosis and other foodborne diseases (campylobacteriosis and listeriosis) from 2012 to 2020 (Maertens de Noordhout et al. 2017). The calculations were based on a Belgian population of 11.2 million people in 2012 and a predicted 11.4 million people in 2020. The estimated DALYs for salmonellosis were 102 (95% uncertainty interval: 8-376) in 2012, or 0.9 DALYs per 100,000 population (95% uncertainty interval: 0.07-3). These were predicted to drop to 82 (95% uncertainty interval: 6-310), or 0.7 DALYs per 100,000 population (95% uncertainty interval: 0.05–3), in 2020.

An Australian study estimated that the total cost of salmonellosis and its sequelae was AUD \$140 million per year (Australian National University 2022). The estimate was based on 2019 data of an estimated 61,600 cases of foodborne salmonellosis, 3,740 hospitalisations and 11 deaths. In addition, the costing was based on an estimated 5,750 cases and 172 hospitalisations due to reactive arthritis following salmonellosis and 5,400 cases and 460 hospitalisations due to irritable bowel syndrome following salmonellosis. DALYs were not reported.

In the EU, the European Food Safety Authority (EFSA) has estimated that the overall economic burden of human salmonellosis may be as high as EUR 3 billion a year.<sup>60</sup>

#### **4.3.3 Overseas studies of *Salmonella* transmission to food-producing animals from animal feed**

As discussed in Section 3.6, certain serotypes from international surveillance data that are frequently isolated from animal feed are among those also commonly isolated from food-producing animals, particularly from poultry. While this type of evidence is primarily circumstantial, investigations have also been carried out that link *Salmonella* contamination of animal feed to subsequent colonisations in a number of animal species. In addition, studies from other countries have assessed the risk posed by feed-borne transmission for different sectors.

##### **Poultry**

Various studies have listed feed as a potential source for poultry colonisation by some *Salmonella* serotypes, and feed has been suggested as the initial source for ongoing contamination by some serotypes in hatcheries and farms (Hoszowski et al. 2016, Wang et al. 2023). For example, *Salmonella* 13,23:i:- is thought to be a recently emerged monophasic variant of S. Idikan, an animal feed-related serotype that can become readily established in feed mills, hatcheries and on broiler farms (Oastler et al. 2022).

In various studies under experimental conditions, poultry feed artificially contaminated with *Salmonella* has led to chicks being colonised with *Salmonella* (Gordon and Tucker 1965,

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<sup>60</sup> [https://www.efsa.europa.eu/sites/default/files/corporate\\_publications/files/factsheetsalmonella.pdf](https://www.efsa.europa.eu/sites/default/files/corporate_publications/files/factsheetsalmonella.pdf); accessed 6 January 2023

Schleifer et al. 1984, Hinton 1988). Concentrations of *Salmonella* of less than 1 CFU/g of feed were sufficient to establish *Salmonella* colonisation in 1-7 day old chicks, while contamination concentrations of 100-300 CFU/g were sufficient to result in colonisation of nearly all birds. In another study, poultry feed was inoculated with either *S. Enteritidis* or *S. Heidelberg* ( $10^4$  CFU/g) and fed to broiler chickens at 14 days of age (Brooks et al. 2021). Tissue samples were collected from birds at 34-41 days. A higher proportion of birds inoculated with *S. Enteritidis* had at least one tissue positive for *Salmonella* (68%) than birds inoculated with *S. Heidelberg* (9%). *S. Enteritidis* was mostly frequently recovered from caeca, followed by cloaca and liver and spleen. *S. Enteritidis* was rarely recovered from edible muscle tissues (breast and thigh). A further study also documented colonisation of chickens that were fed feed that had been inoculated with genetically tagged *S. Enteritidis* (Yang et al. 2017).

In addition to surveillance at a national level linking *Salmonella* serotypes from feed and poultry flocks, the 2011 Risk Profile (Cressey et al. 2011) details a number of studies where common serotypes were found from feed and flocks within the same farms or supply chains (Hacking et al. 1978, Humphrey and Lanning 1988).

Stronger evidence for the feed-borne transmission link to poultry has come from studies where the strains were demonstrated to be genetically related (Shirota et al. 2001). A study examined the epidemiology of the serotype *S. Senftenberg* on 73 commercial poultry farms (40 layer and 32 pullet farms) in Japan over a six-month period during 2008 and 2009 (Shirota et al. 2012). *S. Senftenberg* was isolated from 36 out of 2,896 environmental samples and six out of 427 feed samples from nine pullet farms; the serotype was not isolated from layer farms (15,060 environmental samples and 5,389 feed samples tested) or eggs (218,470 samples tested). Feed and environmental isolates had identical restriction digest patterns following PFGE analysis, indicating that they were closely related. Traceback analyses determined that all positive feed samples arose from a single feed source. Timeline studies showed that contamination occurred first in the feed, then spread to the pullet environment, and to other farms.

In 2011, boot swab samples from layer operations in Austria tested positive for *S. Agona* (Reiter et al. 2012). Distribution of eggs from affected flocks was immediately stopped. The same serotype was isolated from the compound feed provided to the flock. A traceback to feed manufacturers found 44 of 148 soybean meal samples and 14 of 95 poultry feed samples examined were positive for *S. Agona*. PFGE typing identified soybean meal from a particular feed mill in Italy as the source of the flock contamination.

Following detection of the rare serotype *S. Jerusalem* in organic soya feed from Switzerland (2019) and soya expeller from Italy (2020), the serotype was detected in poultry production environments and animals in the two countries during 2020 (Horlbog et al. 2021). WGS determined that feed isolates and isolates from Swiss and Italian poultry flocks belonged to the same sequence type, ST 1028, and were very closely related.

## **Pigs**

Like poultry, pigs are not primarily grazing animals and largely reliant on harvested and/or processed feed year-round. As discussed below, the calculated risk of the transmission of *Salmonella* to pigs via a feed-borne route differs by region; the feed-borne route was considered to play a more important role in studies from Dutch or Scandinavian regions, while studies from other EU regions and the US deemed the risk to be low.

Logistic regression analysis has been used to estimate an odds ratio of 1.6 for the risk of colonisation of pigs with *Salmonella* due to consumption of contaminated or recontaminated

feed in the Netherlands (Berends et al. 1996). It was further estimated that 15-30% of *Salmonella* colonisations in the finishing period may be attributed to feed.

A closed pig production system in Belgium was monitored for *Salmonella* over the course of two years (Korsak et al. 2003). While some serotypes detected in feed were also detected in breeding and fattening pigs and in abattoir carcasses, in general the serotypes most commonly seen in pigs were uncommon (*S. Typhimurium*, *S. Derby*, *S. Anatum*) or not seen (*S. Brandenburg*, *S. Infantis*, *S. Goldcoast*) in feed, while a number of serotypes detected in feed were not subsequently detected in pigs (*S. Bochum*, *S. Hithergreen*, *S. Lexington*, *S. Mbandaka*, *S. Moers*, *S. Odozi*, *S. Plymouth*, *S. Rubislaw*, *S. Schwarzengrund*, *S. Solt*, *S. Utah* and *S. Wien*). The authors concluded that the occurrence of *Salmonella* colonisation of pigs from feedstuffs was very low.

During 2003, a feed-borne outbreak of *S. Cubana* occurred on Swedish pig farms which was traced back to contamination at a feed plant (Osterberg et al. 2006). The strain was detected in 49 of the 77 farms that received the potentially contaminated feed. Feeding soya meal was associated with a higher risk of contamination; at the time of the studies 98% of soybean was imported into the EU from other countries. During a similar period, a second outbreak occurred on 29 pig farms, from feed arising at a second mill owned by the same company (Wierup and Häggblom 2010). Contamination of finished feed was considered to be more likely when *Salmonella* contamination in raw ingredients increased beyond a threshold level. However, a further study from a Norwegian plant that produces soya meal for animal feed mills in Norway, Sweden and Finland, found that a HACCP-based approach was successful in preventing *Salmonella* contamination in finished product despite high levels of contamination of raw ingredients (Wierup and Kristoffersen 2014).

A Bayesian model was employed to trace *Salmonella* contamination in the Finnish pig feed chain (Välttilä et al. 2018). The proportion of *Salmonella* infections in pigs attributable to feed was calculated based on a prevalence of 0.03-0.15% in feed, mean numbers of between  $6.5 \times 10^{-4}$  to 2.5 CFU/g of *Salmonella* when present, and a prevalence of 0.27% (95% CI: 0.09-0.52%) for pigs and 0.54% (95% CI: 0.18-1.2%) for sows. The percentage of *Salmonella* infections attributed to feed was calculated at 38% (95% CI: 9-74%) for pigs (presumably, fattening/market pigs) and 60% (95% CI: 22-93%) for sows (which are larger and consume more feed than fattening/market pigs). A second model based on typing data alone estimated that the feed-borne infections were 29% (95% CI: 3-70%) for pigs and 41% (95% CI: 5-88%) for sows.

A conceptual model of *Salmonella* in the EU pig feed chain has been presented, as a potential prelude to a quantitative microbial risk model (Binter et al. 2011). It should be noted that this study was published shortly after the previous version of the Risk Profile (Cressey et al. 2011) and the prevalence studies summarised by Binter et al. (2011) were largely summarised in the risk profile. The study noted that:

- There are almost no quantitative data on *Salmonella* in commodities of the feed chain (ingredients and finished feed),
- Tracing the source of *Salmonella* contamination is hampered by the risk of cross-contamination as well as various mixing and partitioning events along the supply chain,
- Available information points to contaminated feed ingredients, animal vectors (rodents, birds and insects) and persistent contamination of production environments as important sources of *Salmonella* in feed production,

- Technological procedures such as heat or acid treatment can be used to control *Salmonella* in feed production. However, a large fraction of pig feed is produced without such procedures, and
- Prevention of recontamination and control of moisture throughout the chain are critical factors for controlling *Salmonella* in feed production.

In a US study of *Salmonella* contamination of pig feed, *Salmonella* was detected in 10 of 275 composite feed samples from 8 of 36 barns (Molla et al. 2010). Faecal samples were taken from pigs at the early and late finishing stage, with the prevalence of *Salmonella*-positive faeces decreasing from 1180/6880 (17.2%) at the early finishing stage to 392/5321 (7.4%) at the late finishing stage. Isolates from feed and faeces were characterised by PFGE and antibiotic resistance. Isolates were grouped into five groups on the basis of genetic similarity. Isolates within each group also had the same antibiotic resistance profile. Four of the groups contained isolates from both feed and faecal samples from the same farm.

A review on the transmission of pathogens including *Salmonella* from feed to pigs in the US concluded that there was negligible risk for feed-based transmission of *S. Choleraesuis* (Jones et al. 2020). This serotype causes disease in pigs and is the only serotype considered by the FDA to be an adulterant in pig feed; however, it was not detected in feed from US surveys covered in Table 14 (Li et al. 2012). The risk from feed directly to humans of other serotypes was considered negligible because feed is rarely in contact with immunocompromised people, and most serotypes including *S. Enteritidis* and *S. Typhimurium* also do not cause disease in pigs. However, the risk was considered to be higher for the emerging monophasic serotype of *S. Typhimurium*, *Salmonella* 4,[5],12:i:-. This serotype is frequently resistant to various antibiotics (Appendix A.3), has been detected in US swine feed mills (Magossi et al. 2019) and has been linked to pork product which has resulted in human cases of salmonellosis.<sup>61</sup> They concluded that the risk could be mitigated by excluding high-risk ingredients from facilities, extending biosecurity to feed mills, and considering proactive mitigation strategies.

## Cattle

No overseas studies published since 2011 were found that demonstrated a feed-borne route of transmission of *Salmonella* to cattle. As discussed in the 2011 Risk Profile (Cressey et al. 2011), *Salmonella*-contaminated feed was able to cause colonisation in two dairy cows fed meat and bone meal artificially contaminated with *Salmonella* (*S. Montevideo*, *S. Anatum*, *S. Cerro*, *S. Muenster* and *S. Agona*) at approximately 1000 CFU/g of feed (Bender et al. 1997). All serotypes were intermittently detected in rumen, faecal or necropsy samples from one or both animals, but not from milk samples. No clinical illness was observed.

*S. Mbandaka* was isolated from rectal swabs of cattle from three English dairy farms receiving compound feed from a single feed mill (Jones et al. 1982). *S. Mbandaka* was also isolated from milk filters from two farms, but not from workers in contact with the cattle or wildlife from the surrounding area. Analysis of feed components found *S. Mbandaka* in unopened bags of vegetable fat supplement (palm oil, with palm kernel and ground straw as a carrier base). Numbers of *S. Mbandaka* in two bags of vegetable fat were 240 MPN/100 g. *S. Mbandaka* appeared to be non-pathogenic in cattle and colonisation was only detected in a relatively small number of animals and did not persist beyond one month.

<sup>61</sup> [https://www.cdc.gov/salmonella/pet-treats-07-19/index.html#:~:text=October%2030%2C%202019,with%20pig%20ear%20pet%20treats.](https://www.cdc.gov/salmonella/pet-treats-07-19/index.html#:~:text=October%2030%2C%202019,with%20pig%20ear%20pet%20treats.;); accessed 16 August 2023

Cattle feed contaminated with *S. Infantis* was distributed to Finnish cattle farms during 1995 (Lindqvist et al. 1999). PFGE-based analysis of feed and cattle isolates before and after this incident, allowed discrimination of the feed-associated *S. Infantis* from strains endemic in Finnish cattle. Of the 800 farms that purchased feed from the affected mill, 57 farms tested positive for *S. Infantis*, with the feed-related strain detected in 50 of these farms. Most farms were cleared of this colonisation within 4-6 months. The contamination was not traced to any specific feed component.

In another study, comparison of *Salmonella* from feed components and from cattle faecal isolates from the same farm had identical PFGE types (Davis et al. 2003). Serotypes recovered from feed included *S. Braenderup*, *S. Cerro*, *S. Mbandaka*, *S. Meleagridis* and *S. Typhimurium*. However, in some cases the serotype was found on the specific farm before detection in feed, while in other cases *Salmonella* was detected in feed, but was not detected in cattle.

#### **4.3.4 Overseas studies of *Salmonella* transmission to humans via contaminated from animal feed**

A limited number of outbreaks due to transmission of *Salmonella* from animal feed through animal food product to humans have been reported. However, the circumstances of these outbreaks suggest that many other outbreaks may go undetected, particularly if the serotypes are already common in the human population. It should be noted that in many cases the evidence linking human cases of salmonellosis to the presence of particular serotypes in animal feed is largely circumstantial, but when viewed in aggregation is highly suggestive. Only reports concerning poultry and pigs were located.

##### **Poultry**

The 2011 Risk Profile (Cressey et al. 2011) details three salmonellosis outbreaks that have been linked to poultry feed. These together with more recent reports include:

- **S. Virchow in chicken:** A 1968 outbreak of *S. Virchow* in chicken in Liverpool, England, which involved at least 50 people (Pennington et al. 1968, Semple et al. 1968). The outbreak from the previously rare serotype was traced to dressed chicken from a packing station in Cheshire and associated rearing units. It was hypothesised that the contamination was introduced into chicken breeding units through contaminated feed. *S. Virchow* had previously been isolated from poultry feed components (protein supplements, meat and bone meal, offal meal).
- **S. Agona in chicken:** Prior to 1970, *S. Agona* was a rare serotype in humans. However, by 1972 it accounted for over 500 cases in the US and over 700 cases in the UK. Investigation of a 1972 outbreak of salmonellosis in Arkansas traced the source of infection to a Mississippi poultry farm (Clark et al. 1973). While *S. Agona* was not isolated from feed samples taken from the poultry farm, their feed formulation contained 8% Peruvian fishmeal. Ongoing monitoring of imported feed components identified that Peruvian fishmeal was frequently contaminated with *S. Agona*. During 1969-1970 *S. Agona* also emerged a significant public health issue in UK, Israel and the Netherlands. In all three countries the emergence of this serotype was preceded by detection of the serotype in imported Peruvian fishmeal.
- **S. Hadar in turkeys:** Human isolations of *S. Hadar* were very rare in the UK prior to 1971, but by 1978 accounted for over 14% of all human salmonellosis cases (Rowe et al. 1980, Watson and Kirby 1985). Consumption of turkey meat was identified as a factor in approximately 46% of cases. While the ultimate source was not conclusively identified, *S.*

Hadar was found in the UK in poultry offal meal imported from Israel in 1969 and had become endemic in turkey breeder flocks by the mid-1970s.

- S. Mbandaka in chicken (broilers and layers; Poland): From 1996, *S. Mbandaka* was frequently isolated from animal feed and poultry sources, as well as human cases of salmonellosis in Poland (Hoszowski et al. 2016). PFGE analyses identified that historical isolates of feed and poultry isolates were closely related. A second predominant cluster linked poultry and human isolates.
- S. Mbandaka in eggs (Austria): In 2010, an outbreak of salmonellosis due to *S. Mbandaka* (159 cases) in Austria was epidemiologically linked to consumption of insufficiently heated eggs (Reiter et al. 2012). During the same period, *S. Mbandaka* was detected in a sample of genetically-modified soybean meal taken from a feed manufacturer. PFGE typing of isolates from the human cases and the soybean meal showed that they were closely related but distinct. However, the authors of this study considered that the contaminated soybean meal and subsequent contamination of layer feed was the most probable cause of the salmonellosis outbreak.

## Pigs

Pigs are a recognised vehicle for salmonellosis. Based on data from 2007-2009, the human health risk of salmonellosis attributed to pigs in the EU has been estimated at 31.1%, amounting to 2.9-11 million cases (De Knecht et al. 2015). Although there are no studies demonstrating linkages between human salmonellosis and pig feed, various studies have modelled the contribution from contaminated feed.

It has been estimated that up to 2.1% of human infections acquired in Denmark during 1999-2003 could be attributed to feed-borne serotypes acquired through the consumption of Danish pork and beef (Hald et al. 2004).

Two risk models were used to estimate the proportion of human salmonellosis cases in Finland that may be due to contaminated pig feed (Rönnqvist et al. 2018):

- An exposure model, to estimate pig infections with *Salmonella* based on information on feed contamination and a pig dose-response model (Välttilä et al. 2018).
- An attribution model, using *Salmonella* subtyping data to estimate the proportion of human salmonellosis cases that are due to transmission from pigs.

It was estimated that 14% of Finland's 300-400 annual domestic salmonellosis cases was due to domestic pork and 5.3% (95%CI 1.2-10.3%) was due to pig feed. Finland has strict *Salmonella* control systems. The study also examined the impact on *Salmonella* prevalence in pigs upon relaxation of these measures to a point at which feed contamination was at the EU average. For feed raw ingredients, this would result in an increase in mean estimated prevalence from 0.27% to 0.41%. For finished feed, contamination at the EU mean was estimated to increase the prevalence of *Salmonella* in pigs to a mean of 10.6%.

## 5 REGULATORY CONTROLS

### Key findings

- Detection of *S. Enteritidis* in New Zealand commercial poultry flocks has driven the development of a new regulatory framework for all sectors within the poultry industry to eliminate *S. Enteritidis* from the poultry supply chain where detected. One option for managing chickens from *S. Enteritidis*-positive flocks includes processing for animal or human consumption using a treatment that has been validated to reduce *S. Enteritidis* contamination to an appropriate level. This applies to rendering of chicken material that may be used as an ingredient for animal feed production. There are also requirements around feed management and disposal if feed testing detects *S. Enteritidis*, or if feed is from sheds housing an *S. Enteritidis*-positive flock.
- Other New Zealand regulations and codes of practice set out general requirements for feed manufacturers to manage contaminants in feed materials, during manufacture and final product. Some are specific to controlling *Salmonella* while others will control these bacteria alongside other microbiological hazards.
- International control measures and testing programmes for *Salmonella* in the animal feed industry typically involve implementing, maintaining and documenting procedures based on HACCP principles, and codes for Good Manufacturing Practice. Depending on the region and programme and specific risk of the animal feed, the manufacturing environment, incoming ingredients, and finished product may be tested for *Salmonella*. Further serotyping may be conducted on isolates to inform the risk (for example, serotypes of greater concern to human health or animal species-specific to the animal for which the feed is intended), or for traceback or routine surveillance purposes.

### 5.1 CURRENT CONTROL AND RISK MANAGEMENT MEASURES

#### 5.1.1 Management of *S. Enteritidis*: a regulatory framework

Following the detection of *S. Enteritidis* from New Zealand commercial poultry environments in March 2021 and extensive investigation, a new regulatory framework for the industry has been designed and implemented. The *Animal Products Order: Emergency Control Scheme - Managing Salmonella Enteritidis in Commercial Chicken Flocks (ECS)* was signed on 6 October 2021.<sup>62</sup> The key components of the ECS were to identify *S. Enteritidis*, and facilitate pathogen management, monitoring and verification (Ministry for Primary Industries 2022b). The ECS temporarily covered a regulatory gap present at early stages in the poultry chain; including breeding flocks, hatcheries, rearer farms for future layer birds, layer flocks and broiler farms. The ECS was extended in April 2022 for a further six months and expired on 5 October 2022. The ECS also specified *S. Enteritidis*-related requirements for layer flocks that have had other regulatory requirements in place.

The ECS was replaced by a *S. Enteritidis* regulatory framework to manage long-term risks to public health and international trade from *S. Enteritidis*. This was released under updated Animal Products Regulations 2021,<sup>63</sup> which came into effect on 6 October 2022. The purpose of the *S. Enteritidis* management framework is to detect, manage and assist industry to

<sup>62</sup> <https://gazette.govt.nz/notice/id/2022-sl1236>; accessed 13 January 2023

<sup>63</sup> <https://legislation.govt.nz/regulation/public/2021/0400/latest/LMS520972.html>; accessed 7 June 2023

manage *S. Enteritidis* in commercial poultry flocks as part of routine operations (Ministry for Primary Industries 2022d).

Under the new framework, there are also requirements for poultry feed management (Ministry for Primary Industries 2022a). If there has been an *S. Enteritidis*-positive result from the feed, the producer must dispose of any remaining contaminated feed as soon as practicable; and clean and sanitise all affected feed containers before using them for non-contaminated feed. Feed is no longer considered contaminated if it is subjected to a treatment that is validated as inactivating any *S. Enteritidis*.

The two options for handling chickens arising from an *S. Enteritidis*-positive flock include (Ministry for Primary Industries 2022a):

- Before the chickens are supplied by the processor for human or animal consumption they are subject to a treatment that:
  - has been validated to show that *S. Enteritidis* contamination of the chicken is reduced to an appropriate level [this might include rendering of chicken material that may be used as an ingredient for animal feed production]; and
  - is done in a manner that, as far as practicable, does not contaminate any other chicken, or any equipment or the processing environment; or
- The chickens are disposed of in a manner that ensures that the chickens:
  - do not contaminate other animal material or product, places, equipment, or the processing environment; and
  - cannot enter the human or animal food chain.

### 5.1.2 Current legislations, codes and programmes

The New Zealand animal feed industry is currently regulated by the following legislations and codes.

#### Codes of practice

The NZFMA *Manufacture of Animal Feeds in New Zealand - Code of Practice* was originally issued in March 2000 and the most recent update was prepared in February 2023 (New Zealand Feed Manufacturers Association 2023b). The Code was developed according to the principles of the Codex Alimentarius Code of Practice on Good Animal Feeding (Food and Agriculture Organization of the United Nations 2020). This Code does not replace legislation, but it does highlight the purposes and the key components of various Acts that apply to feed manufacture. The Code is not mandatory, but compliance to its principles will help feed manufacturers apply Good Operating Practice within their operations, and will constitute Good Manufacturing Practice.

There are areas of the Code pertaining indirectly or directly to the control of *Salmonella*. These include the following, with more detail included in Appendix C.1:

- The design of the feed mill and equipment, such as good drainage and attention to eliminating wet areas and ensuring that feed does not get wet, effective cleaning.
- Cleaning and sanitation.
- Pest and vermin control.
- Worker hygiene.
- Purchasing specifications of feed ingredients. Specific procedures depend on the feed ingredient and destination feed type, and include purchasing ingredients that do not contain *Salmonella*.

- HACCP overview and *Salmonella*-specific requirements during milling.
- Traceability and recall procedures.

The Code also includes guidance for the collection of feed product and environmental samples for *Salmonella* testing. Specific guidance covers obtaining a representative sample (for product), the use of sterile technique and sampling equipment to avoid sample contamination, and sample labelling. Sampling frequency is determined by the feed manufacturer according to their individual situation, and taking account of their equipment in use. Although not specified in the Code, the *Salmonella* serotype is typically determined, but only *S. Enteritidis* is regulated (Kerry Mulqueen, PIANZ, pers. comm., June 2023).

The NZFMA introduced the FeedSafeNZ accreditation programme in 2015 to ensure the quality of animal feed produced in New Zealand.<sup>64</sup> The programme tests the ingredients, additives and processes used by feed manufacturers. Individual feed mills operate a *Salmonella* surveillance programme to ensure feed is free from *Salmonella*. The programme includes an on-site audit of ingredients, plant, storage and operations. The programme requires producers to meet minimum standards specified by the NZFMA Code of Good Manufacturing Practice.

There is also a Code of Practice for Rendering (New Zealand Food Safety Authority 2009). *Salmonella* is amongst the hazards controlled under the Code. Relevant to *Salmonella*, the Code specifies:

- That buildings, facilities and equipment are designed, constructed, installed and operated in a manner that prevents or minimises contamination of animal products, packaging, equipment, and the processing environment. For example, there are controls for preventing rain water entering loading bay areas, dry cleaning, and adequate ventilation to vent steam and condensation, to prevent moisture accumulation that might promote *Salmonella* growth. This also includes control of pests.
- A health policy requires notification and restricted activities and work areas for workers with gastrointestinal illness including salmonellosis.
- That processes are validated.
- Rendered meals derived from medium-risk material (which includes poultry flocks that are *S. Enteritidis*-positive) intended for animal consumption are subject to post-production testing for *Salmonella* which includes a composite of samples of approximately 250g collected on every production day. *Salmonella* must be not detected from 5 x 25 g samples as tested by laboratory with International Accreditation New Zealand (IANZ) accreditation for *Salmonella* testing. If *Salmonella* is detected, the rendering plant operator must undergo a review of hygienic procedures for potential post-thermal processing contamination.

## Legislation

The importation, manufacture, sale and use of animal feed in New Zealand is regulated under the *Agricultural Compounds and Veterinary Medicines Act 1997*, the *Animal Products Act 1999* and the *Biosecurity Act 1993*. These Acts are administered by MPI.

The purpose of the *Agricultural Compounds and Veterinary Medicines Act 1997* is to prevent or manage risks associated with the use of “agricultural compounds” which includes animal feed (designated oral nutritional compounds).<sup>65</sup> Requirements for feed include complying with

<sup>64</sup> <https://www.nzfma.org.nz/feedsafe-nz/>; accessed 7 June 2023

<sup>65</sup> <https://www.legislation.govt.nz/act/public/1997/0087/latest/whole.html>; accessed 7 June 2023

minimum manufacturing requirements, ensuring that feed is fit for purpose, specified information is contained on the product label, that it meets certain requirements for oral nutritional compounds, and that it is not misrepresented as anything other than animal feed. Regulations cover both imported and domestically produced material, and includes feed of animal origin, feed of plant origin, and combinations of the two.

The *Biosecurity Act 1993* regulates exclusion, eradication and management of pests and unwanted organisms.<sup>66</sup> Two sets of regulations under this Act apply to animal feed that contains animal product ingredients:

- The *Biosecurity (Ruminant Protein) Regulations 1999* prohibits feeding of ruminant protein to ruminants and was introduced in response to the BSE outbreak in Europe.<sup>67,68</sup>
- The *Biosecurity (Meat and Food Waste for Pigs) Regulations 2005* sets out the rules for feeding meat or food waste containing meat to pigs, and was designed to limit the spread of diseases like African Swine Fever or foot-and-mouth disease if they ever get to New Zealand.<sup>69</sup> Such food waste must be heated to 100°C for 1 hour, for example by boiling, before it can be fed to pigs (both commercial and backyard pigs).

There are also various Import Health Standards for feed components that have been issued under the *Biosecurity Act 1993*, for example:

- The *Import Health Standard: Grain and seeds for consumption, feed or processing* specifies the requirements for the importation of grains and seeds for consumption, feed or processing (Ministry for Primary Industries 2023b). All imported grains and seeds must be free from regulated pests<sup>70</sup> and contaminants. There are additional requirements if the grains and seeds destined for pig or ruminant consumption are from a country that is not officially free of foot-and-mouth disease.
- The *Import Health Standard: Processed animal feed of plant origin* describes the phytosanitary requirements that must be met for the importation of plant products for animal feed from all countries to be given biosecurity clearance into New Zealand (Ministry for Primary Industries 2022c). Depending on the feed ingredient, requirements may include:
  - Processing in a facility that does not process animal ingredients.
  - Heat treatment; for example, the core temperature of the product should be raised to at least 85°C for a minimum of 5 minutes, or at least 30 seconds for full fat soybean meal or maize meal, or undergone a minimum of 30 seconds pelleting at this temperature for pelleted product.
  - Does not contain viable seeds.
  - For product shipped in bulk, there should be no contamination by unprocessed plant material, vermin, birds, faecal material and other animal products and visually detectable regulated pests. The product should have also been stored and transported in a manner that prevents contamination by these.
  - Documentation and certification; for example, a phytosanitary certificate and manufacturer's certificate.

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<sup>66</sup> <https://www.legislation.govt.nz/act/public/1993/0095/latest/DLM314623.html>; accessed 7 June 2023

<sup>67</sup> <https://www.legislation.govt.nz/regulation/public/1999/0410/latest/whole.html>; accessed 7 June 2023

<sup>68</sup> <https://www.mpi.govt.nz/animals/animal-feed-preventing-disease-transfer/ruminant-protein-control-programmes/>; accessed 7 June 2023

<sup>69</sup> <https://www.legislation.govt.nz/regulation/public/2005/0150/latest/DLM332617.html>; accessed 7 June 2023

<sup>70</sup> <https://pierpestregister.mpi.govt.nz/>; accessed 1 August 2023

- The *Import Health Standard for poultry feather and products containing poultry feather meal for animal feeding from Australia* (Ministry for Primary Industries 2010). This requires that the consignment originates from birds that were kept in premises and slaughtered in a plant located in an area free from Notifiable Avian Influenza and Newcastle Disease. There are no requirements around *Salmonella* status of flocks. However, processing of the feather meal requires that the product has been subjected to a core temperature of at least 100°C for 25 minutes, or an equivalent treatment, which would kill any *Salmonella* present.
- There are a number of *Import Health Standards* for dairy products not for human consumption from different countries.<sup>71</sup>

The *Animal Products Act 1999* regulates the processing of animal material into products for use, trade, and export through managing associated risks and facilitating overseas market access.<sup>72</sup> As such, this does not apply to the manufacture of feed containing only plant material. The major focus is on primary processing, but also covers on-farm production and secondary processing.

A redesigned *Animal Products Regulations 2021*<sup>73</sup> was introduced under the *Animal Products Act 1999* and came into force on 6 October 2022. The purpose of the redesign was to simplify and consolidate existing Regulations under the Act. *The Animal Products Notice: Production, Supply and Processing* was issued for the purpose of supplementing the *Animal Product Regulations 2021* (Ministry for Primary Industries 2022a). Relevant to the animal feed industry, it covers requirements or restrictions for:

- The supply of animal material for animal consumption, for example if the supplier has reason to believe that the animal material may have residue levels of any chemical (which might include veterinary medicines), or have been exposed to feed or environmental contaminants, which may be harmful to animals upon consumption.
- The supply and treatment of medium risk animal material before it is used for animal consumption. Examples of medium risk animal material includes that which might contain chemical contaminants, or arises from diseased animals or flocks slaughtered for disease eradication purposes, animals that have died in the field, homekill or recreational catch.
- Supplier declarations for the producer that contains information such as details of the supplier, and the history of the animals that might be relevant to the safety of product from that animal. Specific detail depends on the type of animal but might include whether they were born on the property or imported, appear on any national disease surveillance or residue suspect list, and colony/flock/herd health procedures.
- Who can kill animals for animal consumption, and for ante-mortem and/or post-mortem examination.
- Transport of animals or animal products.
- Processing animals, including rendering and mechanical separation. There are also requirements for chickens from flocks that have tested positive for *S. Enteritidis*. Before the chickens are supplied to the processor, they must be treated in a way to reduce contamination of *S. Enteritidis* to an appropriate level (although the level is not defined) and does not contaminate any other chickens or processing equipment. Alternatively, the chickens must be disposed of so that they do not contaminate other chickens, equipment, or enter into the animal chain.

<sup>71</sup> <https://www.mpi.govt.nz/legal/compliance-requirements/ihs-import-health-standards/>; accessed 2 August 2023

<sup>72</sup> <https://www.legislation.govt.nz/act/public/1999/0093/latest/DLM33502.html>; accessed 7 June 2023

<sup>73</sup> <https://legislation.govt.nz/regulation/public/2021/0400/latest/LMS520972.html>; accessed 13 January 2023

Manufacturers of animal products, including those destined for animal feed, are required under the *Animal Products Act 1999* to operate under an RMP. The Act defines an RMP as a programme designed to identify and control, manage, and eliminate or minimise hazards and other risk factors in relation to the production and processing of animal material and animal products in order to ensure that the resulting animal product is fit for intended purpose. An RMP is based on HACCP principles of: identifying the hazards, the systems of control, and demonstrating that the controls are effective (Ministry for Primary Industries 2022e). The Act requires that RMPs are tailored for each animal product business according to the animal materials used, the processes performed and the product range produced. Operators must build any relevant regulatory limits (for example, microbiological limits) into their RMP, but can also set their own measurable limits to ensure the feed or food is safe and fit for purpose.

### **5.1.3 Testing programmes and control measures in other countries**

International control measures and testing programmes for *Salmonella* in the animal feed industry have been described in more detail in Appendix C.2. Specific details differ between regions, but programmes typically involve implementing, maintaining and documenting procedures based on HACCP principles, and codes for Good Manufacturing Practice. Depending on the region and programme and specific risk of the animal feed, the manufacturing environment, equipment, incoming product, and finished product may be tested for *Salmonella*. Consequences of a positive test for *Salmonella* were not found for all regions, but in Canada, finished livestock feed that tests positive for *Salmonella* (any serotype) is considered non-compliant. Although not required by any programmes assessed, further serotyping may be conducted on isolates to inform the risk (for example, serotypes of greater concern to human health such as *S. Enteritidis*, or of concern to the species of animal intended to be provided the feed, or for traceback or routine surveillance purposes).

## 6 EVALUATION OF RISK

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### 6.1 RISK ASSESSMENTS

#### Key findings

- No New Zealand quantitative risk assessments have been conducted for *Salmonella* in animal feed for the period from 2011 to present. MPI have reviewed and provided updated guidance on requirements for pathogen inactivation using the procedures used to produce imported animal product that may be used in feed.
- Risk assessments and risk factor analyses from other countries are provided in Appendix B.5. Section 4.3 also describes various models that have examined the risk of feed-borne transmission to animals and humans.

#### 6.1.1 Risk assessments and risk related activities for *Salmonella* in animal feed

Quantitative or qualitative risk assessments are structured science-based processes that estimate the probability and severity of illness from consuming food containing biological, chemical or physical contaminants, and guide risk management interventions. There are no formal New Zealand quantitative risk assessments considering *Salmonella* in animal feed since 2011.

Although not a quantitative risk assessment, the Biosecurity New Zealand's Animal Risk Assessment team conducted a technical review of animal feed and processing methods with a focus on processing parameters for retorting, extrusion-cooking, baking and chemical treatment in the production of animal feed from animal-derived material (Ministry for Primary Industries 2021c). This review identifies the acceptable minimum process parameters required to control risk pathogens, such as *Salmonella*, that are associated with animal origin raw materials. The work was focussed towards controlling risks from imported feed materials but is also applicable to the domestic supply. Each process was assessed for its capacity to inactivate the most heat-stable and chemical-tolerant pathogens likely to be present. Risk management recommendations relevant to this Risk Profile include:

- Retorted animal feed: a heat treatment equivalent of at least  $F_0^{74}$  of 2.8 must have been applied with a temperature at the slowest heating point reaching a minimum of 100°C within the hermetically sealed container.
- Extrusion-cooked product: Heat treatment within the extrusion chamber to achieve a:
  - thermal treatment that is equivalent to  $F_0$  value of 2.8, or
  - thermal treatment equivalent to heating at 70°C for 30 minutes for raw material excluding poultry ingredients, or
  - thermal treatment equivalent to heating at 100°C for 25 minutes for raw material containing poultry ingredients.
- Dry palatants (ingredients designed to improve food consumption, for example by improving taste or smell): Heat treatment at 100°C for 30 minutes.
- Liquid palatants: acidification process at pH 2.7–3.7.

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<sup>74</sup>  $F_0$  value is the measure of the amount of lethal heat which results from a specified thermal process, and is the lethal effect equivalent to the number of minutes at 121.1°C when assuming instantaneous heating and cooling and a z-value of 10°C. The z-value is defined as the temperature change (in degrees) required to reduce or increase the D-value by one decimal.

In addition, the document substantiates the decision to restrict imports of animal-feed products that have been freeze-dried, chilled or high-pressure processed because these processes do not sufficiently inactivate pathogens. For gamma-irradiated products, although irradiation sufficiently inactivates pathogens, it is also considered unacceptable because it results in a significant loss of nutritive value of product. The information supports Import Health Standards governing the import of animal feed into New Zealand (Section 5.1).

The MPI Animal Risk Assessment team have also written technical advice on the inactivation of microbes in animal-origin raw materials used to produce animal feed, based on the aforementioned technical review (Ministry for Primary Industries 2021b). The animal-origin raw materials considered include red meat (pigs, cattle, sheep, goats, deer and buffalo), avian meat (chicken, duck, turkey, geese, quail, ostrich), fish (cod, salmon, trout, tuna, shrimp), kangaroo and crocodile meat, dairy products and eggs. The document presents parameters for the thermal and chemical inactivation of microorganisms that may be present in raw materials.

### **6.1.2 Risk assessments for *Salmonella* in animal food products**

Since the 2011 Risk Profile was produced, Risk Profiles (including updates) with *Salmonella* as the hazard have been produced for the most commonly suspected food transmission vehicles:

- Poultry meat (Kingsbury 2023a);
- Eggs (Lake et al. 2011, Rivas et al. 2016, Kingsbury 2023b); and
- Raw milk (Soboleva 2013, 2019).

The 2023 Risk Profile concerning broiler chickens and poultry meat reported that the very low prevalence of *Salmonella* detected by the NMD programme suggests that the risk of salmonellosis from poultry meat remains low (Kingsbury 2023a). The apparent increased frequency of poultry meat consumption has increased the risk of potential exposure, but this does not appear to have increased the risk of illness as reflected in salmonellosis notification rates. Earlier Risk Profiles considering *Salmonella* in poultry products were conducted before *S. Enteritidis* had been detected in poultry flocks in New Zealand. The 2023 Risk Profile concluded that the detection of the *S. Enteritidis* DT8, ST11 strain in poultry has the potential to increase the risk to the New Zealand broiler industry and to consumers of broiler poultry product. The potential for transovarian transmission of *S. Enteritidis* to eggs via the breeder flocks at the apex of the supply chain could result in widespread dissemination through the supply chain, and to consumers of contaminated poultry meat product. International studies indicate that *S. Enteritidis* might be more infectious, and higher hospitalisation rates suggest that this strain of *S. Enteritidis* poses a greater risk to human health compared with other *Salmonella* serotypes. There is also a risk to the international trade in hatching eggs and broiler product.

The 2011 and 2016 Risk Profiles concerning eggs found there was little evidence that transmission of *Salmonella* via eggs was a significant transmission route occurring in New Zealand (Lake et al. 2011, Rivas et al. 2016). The 2023 Risk Profile update similarly found that the risk associated with non-Enteritidis *Salmonella* serotypes in and on eggs had not changed (Kingsbury 2023b). However, detection of the *S. Enteritidis* DT8, ST11 strain SE\_2019\_C\_01 in layer flocks also has the potential to increase the risk to the New Zealand layer industry and to consumers of eggs. The level of risk of this strain for broiler flocks and layer flocks, poultry meat and eggs will be determined by the efficacy of the new control

measures implemented to detect flock colonisation, manage colonised flocks, and control any dissemination of *S. Enteritidis*.

The raw milk Risk Profiles also consider pathogens in addition to *Salmonella*. The 2013 report reaffirmed earlier findings that the consumption of raw milk was a significant source of risk to human health, particularly in regard to food poisoning caused by Shiga toxin-producing *E. coli* and *Campylobacter* (Soboleva 2013). The 2016 update reported that the main microbiological hazards present in raw milk in New Zealand have not changed since the 2013 risk assessment; salmonellosis was the fourth most notified enteric disease associated with the consumption of raw milk (Soboleva 2019).

A discussion document has also reviewed and collated information from New Zealand and overseas regarding microbial pathogens, including *Salmonella*, in commercially available raw meat pet food (Rivas et al. 2023). In contrast to this Risk Profile where meat used in animal feed has undergone a heat treatment step to inactivate pathogens, raw meat pet food product is defined as: “where animal material (meat, offal, bone) either singly or in combination with other ingredients has not undergone a processing step or treatment beyond boning, slicing, dicing, mincing, mixing, forming, chilling or freezing”. As such, the presence of microbial pathogens in these products poses a risk for both human and animal health. The practice of feeding these products to pets is increasing, and consequently, the exposure of animals and humans to pathogens present in the products is also increasing. However, there are limited prevalence data for these microbial hazards in raw meat pet food products available in New Zealand. There have also been no reported human outbreaks of salmonellosis or other infectious diseases from these products in New Zealand, although outbreaks have been reported in other countries.

## 6.2 EVALUATION OF RISK FOR NEW ZEALAND

### Key findings

- **RMQ1:** There are a wide range of systems in place in New Zealand to control microbiological hazards such as *Salmonella* in feed materials and finished feed, including import requirements for feed materials, and legislative controls, codes of practice, and heat treatment steps during feed manufacture. Despite these controls, *Salmonella* contamination of feed materials (which might be fed directly to animals) and finished animal feed is detected at a low level in New Zealand. Therefore, animals are likely to be exposed to *Salmonella* through consumption of the contaminated feed, which presents a risk of becoming colonised by this species. While the ability of animals to become colonised with *Salmonella* through consumption of contaminated feed has been demonstrated, there is insufficient information on the prevalence and numbers of *Salmonella* contamination of feed in New Zealand and the associated dose-response relationships for various animal species to estimate the extent of the risk. However, the risk is likely to be low based on the low level of detected *Salmonella* contamination of feed. Less processed feed produced by individual farms for their own purposes might carry a higher risk for *Salmonella* contamination and consequently, an increased exposure to animals.
- **RMQ2:** Despite the 2021 detection of *S. Enteritidis* in chicken product and in the chicken production environment, the risk of introduction of *S. Enteritidis* into food-producing animals through feed is considered to be very low. Material from *S. Enteritidis*-positive

flocks can be sent for rendering for use in animal feed. However, thermal processes during rendering and feed pelleting processes are expected to inactivate any *S. Enteritidis* that might be present in raw feed ingredients, and this serotype is not commonly associated with animal feed or feed mill environments internationally. Poultry meal was not used for the production of animal feed in 2021 and 2022, and usage was limited to home-milled pig feed in previous years. *S. Enteritidis* has not been detected in feed or raw ingredients for the period assessed in this report (2011-2022) and was not reported in the 2011 Risk Profile. There is also no evidence that any food-producing animals have been infected by the outbreak strain via a feed transmission route.

- **RMQ3:** The potential for human cases of salmonellosis to result from exposure to foods arising from animals colonised with *Salmonella* is well-known, and it follows that any feed-borne transmission to food producing animals could result in flow-through transmission to humans. Given the intensive nature of poultry and swine rearing (which allows for transmission of *Salmonella* between animals in a herd/flock) and their dependence on compound feed, combined with the increasing consumption of poultry and pork products by New Zealanders, there is potential for an on-farm contamination event to be magnified through the food chain. Only one outbreak of human salmonellosis due to transmission from animal feed via animal food product to humans has been reported in New Zealand. Internationally, only a limited number have been reported, which were via poultry and swine feed and food chains. However, human salmonellosis is not likely to be attributed to a feed source, particularly if the serotypes are already common in the animal and human population. Serotypes commonly isolated from feed ingredients and finished feed are observed from both food-producing animals and human cases of salmonellosis in New Zealand. Therefore, there is sufficient evidence that *Salmonella* present in animal feed presents a risk to consumers of animal products from livestock receiving contaminated feed, but there is insufficient evidence to quantitatively determine the level of risk.
- **Data gaps:** A greater understanding of the potential for *Salmonella* transmission via a feed-borne route to animals and humans could be obtained from more data on the prevalence and numbers of *Salmonella* in feed and feed components in New Zealand; prevalence of feed-associated serotypes within primary production of food-producing animals and from product at retail; and from WGS analyses linking *Salmonella* isolates from feed, food-producing animals, food produced from those animals, and humans.

While *Salmonella* can cause illness in animals it is more common for these bacteria to colonise the intestinal tract, with subsequent faecal excretion. It is this intestinal colonisation that presents a higher risk of *Salmonella* being transferred to food, either through carcass processing or contamination of eggs or milk. RMQ1 considers the first part of the food chain, the risk of *Salmonella* being introduced to livestock via feed. RMQ2 specifically considers the implications of *S. Enteritidis* being detected in New Zealand poultry and the importance of feed in controlling this serotype. RMQ3 considers the second part of the food chain, that being the subsequent risk of onward foodborne transmission to humans.

### 6.2.1 RMQ1: What is the risk of introduction of *Salmonella* into food-producing animals (poultry broilers and layers, cattle, sheep, pigs) by contamination of feed?

The feed types considered in this Risk Profile are predominantly non-pasture and non-fodder-based, with a primary focus on compound feeds and feed materials. Compound feed is made from a range of ingredients, depending on the animals that the feed is intended for. Compound feed is usually made from grains and other plant-based materials (possibly including food by-products or concentrates such as PKE, molasses and oils), and might also include rendered animal-based materials. Some of these materials are also fed directly to food-producing animals.

Data are available to show that *Salmonella* can be detected in feed materials and in compound feed both in New Zealand and internationally. *Salmonella* survive well in dry conditions present in feed. Some serotypes are also more tolerant to desiccation and high temperatures, so are more likely to survive when heat treatments are not sufficient for a complete microbial kill.

International studies show that the prevalence of *Salmonella* is higher in feed materials compared with finished feed, but the range of these prevalence values is wide across studies. Higher *Salmonella* prevalence values tended to be reported for animal-based materials such as fish meal and meat/bone meal (as high as 84% and 48%, respectively), and for plant-based products like cottonseed, canola meal and soybean meal (22% or lower). These data show that animals can be exposed to *Salmonella* through direct feeding of these materials. However, prevalence data was more limited for *Salmonella* in feed materials fed directly to New Zealand food-producing animals. These feed materials are sourced through imported and domestic supplies. There are requirements for importers to control hazards such as *Salmonella* in incoming feed materials but no data were located to indicate the level of *Salmonella* contamination, including at the farm level.

Heat treatment steps are included during the rendering of animal product and the manufacturing (the pelleting step) of compound feed in feed mills. Within New Zealand, there are also legislative controls and Codes of Practice to control health hazards in these premises, including *Salmonella*. These controls reflect an awareness of the risk of *Salmonella* contamination of feed. International surveys of feed mills published in the scientific literature demonstrate that *Salmonella* can contaminate the process line and feed mill environment. This provides opportunities for feed to be re-contaminated after heat treatment, or to remain contaminated due to product build up in the line and/or ineffective heat treatment. There are also opportunities for feed to be contaminated during transport, storage and on-farm use.

A New Zealand testing regime of both ingredients and finished feed for the poultry industry has been in existence for many years and shows a variable prevalence of *Salmonella* of less than 5% (for example, 1.0% of finished poultry feed and raw ingredient samples were *Salmonella* positive, n=45,438, 2011-2022). Other available data for New Zealand shows that *Salmonella* can occasionally be detected in finished feed for other animals, and in meat/bone meal feed material. Similar data for the other feed-dependent livestock, pigs, are not available. There is a (probably small) proportion of feed production by individual farms for their own purposes that is potentially less processed, and this might present a higher risk route for *Salmonella* infection of livestock.

In New Zealand, the poultry sector is the largest user of finished compound feed, followed by pigs, dairy cattle and calves. Poultry and pigs are non-grazing species and rely on supplemented feed; thus have the greatest exposure to feed that might be contaminated with *Salmonella*. However, supplementary feed use is increasing in the dairy industry. The ability

of *Salmonella* to colonise animals through consumption of contaminated feed has been demonstrated internationally, through both experimental investigations and studies of real-world incidents. In New Zealand, the use PKE meal (which is imported) as a cattle supplementary feed was significantly associated with a herd-level outbreak of salmonellosis, although the role of the feed relative to other contributory factors could not be clarified.

Key information is not available to estimate the risk of *Salmonella* being introduced into food producing animals via feed. Primarily, there is insufficient information on the prevalence and levels of *Salmonella* contamination of feed in New Zealand. Estimating risk is further complicated because intestinal colonisation depends on many factors, including the serotype(s) of *Salmonella*, the age of the animal, health status and species, the existing intestinal microbiome, and the type and amount of feed consumed. Establishing whether animals have been colonised also requires large surveys, since many of the animals will not become infected, nor visibly sick. It is only possible to say at this stage that *Salmonella* in animal feed does present a risk of animals becoming colonised by this species.

Further circumstantial evidence supports this occurring in New Zealand. *Salmonella* serotype data from New Zealand show that some of the same serotypes dominant in animal feed are also dominant in food-producing animals and their meat. However, there are other routes of transmission that could account for this. This is also seen from international surveillance data.

### **6.2.2 RMQ2: Considering the detection of *Salmonella* Enteritidis in chicken products and on farms, has the risk of introduction of *Salmonella* into food-producing animals changed since the 2011 Risk Profile update?**

While this question specifically considers the risk from *S. Enteritidis*, it is possible that risk management interventions following the incursion of *S. Enteritidis* SE\_2019\_C\_01 into New Zealand poultry (such as improved biosecurity procedures) have also impacted other *Salmonella* serotypes.

Poultry flocks that are positive for *S. Enteritidis* may be processed for animal consumption in a manner that reduces the *S. Enteritidis* contamination and does not contaminate other poultry, equipment or processing environments in the process (Ministry for Primary Industries 2022a). This means that positive flocks can be processed by rendering prior to use in animal feed. Assuming equipment is functioning to specifications, the heat treatment parameters used for rendering and subsequently at the feed mill, should be sufficient to inactivate any *Salmonella* present in poultry material (Section 2.4). *Salmonella* recontamination of rendered product and processed feed can occur post-processing, and one source for the contamination is the unprocessed materials, emphasising the importance of careful adherence to procedures that minimise any contamination from the *S. Enteritidis* positive flock. In addition, new regulatory requirements for the poultry industry include establishing an RMP, microbiological testing of the poultry environment for *S. Enteritidis*, and tracing and elimination of *S. Enteritidis* from the poultry supply chain if it is detected. These procedures are focused on elimination of this microbiological hazard, reducing the opportunities for *S. Enteritidis* to spread through New Zealand's vertically-integrated poultry industry, and consequently reducing the likelihood that raw poultry material contaminated with *S. Enteritidis* enters processing.

Given the significant potential economic effects of the spread of *S. Enteritidis* in New Zealand it is likely that the controls on poultry material being made into animal feed ingredients will be strongly adhered to by industry.

Although poultry fat was used, poultry meal (rendered poultry product) was not used in the production of animal feed in New Zealand during 2021 and 2022, and only a fraction of the volume of poultry meal was used in 2020 relative to earlier years (Section 2.2). When used, poultry meal was only used in pig feed, but not in poultry or calf feed. Therefore, there has been very limited opportunity for material that might have arisen from *S. Enteritidis*-positive poultry flocks to enter feed chains.

While *S. Enteritidis* was detected in poultry in New Zealand for the first time in 2021, other strains of this serotype have been isolated from other livestock species prior to this time. Since 2011, there have been 38 isolations of *S. Enteritidis* from bovine, caprine and ovine species based on ESR ERL surveillance data.<sup>75</sup> Most isolates up until 2019 were DT11 (with the exception of three ST9a and seven DT1 isolates in 2011 and 2012, respectively). After 2019, phage typing has ceased and no further typing is provided unless strains undergo sequencing, which provides a ST. Therefore, even before the *S. Enteritidis* outbreak associated with poultry, there was potential for feed to be contaminated with *S. Enteritidis* arising from other rendered product from other animal species used in feed.

Rendered feed product and finished feed are routinely tested for *Salmonella* in New Zealand. Although other serotypes of *Salmonella* have been isolated from animal meal and finished feed in New Zealand, there have been no isolations of *S. Enteritidis* from these materials for the years assessed (2011 to 2022; Section 3.1, Table 8, Table 9, Appendix A.2). There is also no evidence of transmission of the *S. Enteritidis* SE\_2019\_C\_01 outbreak strain via contaminated feed to non-poultry, food-producing animals in New Zealand. The strain has been isolated from a single cow and goat, as well as rodents and hedgehogs, but all were epidemiologically linked to *S. Enteritidis*-positive poultry farms (Ministry for Primary Industries 2021a, Kingsbury 2023b). The outbreak strain was also isolated from two cats which were not associated with *S. Enteritidis*-positive farms, but the source of transmission was not identified.

There is currently no evidence that detection of *S. Enteritidis* in chicken products and on poultry farms has changed the risk of *Salmonella* being introduced to food-producing animals via feed. However, if extensive culling of *S. Enteritidis*-positive flocks occurs and these birds are sent for rendering without careful control and monitoring, there will be an increased risk of onward transmission to other food animals via feed.

Internationally, contaminated feed has been implicated as the source of *Salmonella* colonising animals; particularly poultry flocks. However, this is typically by non-*Enteritidis* serotypes such as *S. Senftenberg*, *S. Mbandaka*, *S. Anatum*, *S. Rissen*, *S. Kedougou* and *S. Tennessee*. These serotypes are typically more desiccation-tolerant and/or heat-tolerant, and are isolated at much higher frequencies from feed materials, finished feed and feed mill environments than *S. Enteritidis* (Table 14, Table 15, Appendix A.3).

### 6.2.3 RMQ3: What is the flow-on effect for human exposure?

It is well-established that people can develop salmonellosis through consuming foods derived from animals that had been colonised with *Salmonella*. There are high numbers of human cases of salmonellosis reported in New Zealand each year (708-1,188 cases for the years 2011 to 2022), of which 62% are estimated to be foodborne (Cressey et al. 2019). One study estimates that up to 85% of salmonellosis cases in New Zealand could be attributed to cattle, poultry, sheep or pigs as the primary source (French et al. 2013) (Section 4.2). Yet, there are

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<sup>75</sup> <https://www.esr.cri.nz/our-research/nga-kete/infectious-disease-intelligence/enteric-reference-testing/non-human-salmonella-isolates/>; accessed 9 August 2023

relatively few outbreaks each year where a suspected vehicle of transmission is identified, and even fewer where there is strong evidence for that vehicle. These vehicles are not necessarily animal products, raising a further complication in assessing the contribution of contaminated animal feed to human salmonellosis. Animal faeces containing *Salmonella* can contaminate other food production areas such as fresh produce fields, with subsequent human illness. The question of whether contaminated feed has a role at the start of this chain of events is very difficult to answer. There has only been one reported New Zealand incident where the cause of human foodborne salmonellosis cases was linked to contaminated animal feed, specifically *Salmonella* in poultry feed (Wong 2003).

Internationally, there are some human salmonellosis outbreaks linked to transmission of *Salmonella* from animal feed, through animal food product, to humans. These predominantly involved the poultry and swine feed and food chains. As mentioned above, these animal species have a higher exposure to potentially contaminated compound feed compared with predominantly forage-fed livestock. The importance of feed-borne transmission of *Salmonella* to pigs and poultry in New Zealand is not known. However, if this is occurring, the increased consumption of both poultry meat and pork since 2011 will be important for human exposure. Outbreaks occurring via a feed-borne route are likely going undetected, particularly if the *Salmonella* serotype causing illness is a common cause of salmonellosis in the human population.

There is sufficient evidence that *Salmonella* present in animal feed presents a risk to consumers of animal foods from animals receiving contaminated feed. However, there is insufficient evidence to quantitatively determine the level of risk. Qualitative evaluation is limited to a discussion of relative risk. Due to control steps along the production chain for compound feed, and current evidence suggesting that *Salmonella* prevalence in these feeds is low, the risk to consumers appears to be low. However, given the intensive nature of poultry and swine rearing (which allows for transmission of *Salmonella* between animals in a herd/flock) and their dependence on compound feed, combined with the increasing consumption of poultry and pork products by New Zealanders, there is potential for an on-farm contamination event to be magnified through the food chain. Serotypes commonly isolated from feed ingredients and finished feed are observed from both food-producing animals and human cases of salmonellosis in New Zealand, although this evidence is not proof of causation. Evidence for this comes from data from other countries on *Salmonella* prevalence in feeds since there are no data for New Zealand. It is also possible that supplementary feeding of non-compound feeds is contributing to *Salmonella* prevalence among food animals and onward transmission through the food chain.

Stronger evidence would come from the use of finer typing methods such as WGS during routine surveillance to reveal linkages between isolates from animal feed, food production animals, and human cases.

#### **6.2.4 Data gaps**

Data gaps identified during the production of this Risk Profile include:

- *Salmonella* prevalence in animal feed. Some data are available but these have limitations. Data from the ESR ERL are limited to the serotypes detected from poultry and non-poultry feed, and meat and bone meal ingredients (Table 8). Data from the poultry industry provides an overall prevalence but results for feed ingredients and finished feed are reported together, which does not inform on the exposure to poultry via the finished feed. Data on the prevalence of *Salmonella* in other feed types (which also includes feed

produced and used on the farm), or imported feed ingredients and finished feed, are not available for New Zealand. There are also no data showing the numbers of *Salmonella* in feed, which would inform on the dose to which animals are exposed.

- *Salmonella* prevalence in animals and animal product. The main source for prevalence data for non-Enteritidis *Salmonella* on poultry and red meat is the NMD programme during animal processing. There are no routine surveillance data on the prevalence and serotypes of *Salmonella* occurring during animal primary production (although environmental testing for *S. Enteritidis* now occurs on poultry farms and hatcheries). There are also no recent data on the prevalence, numbers and serotypes of *Salmonella* occurring on animal product at retail, which better represents the prevalence and numbers to which consumers are exposed.
- Finer typing of isolates to draw linkages between *Salmonella* from feed, animals and humans. Finer typing methods such as WGS have the potential to identify linkages along the whole feed and food chain (*Salmonella* occurring in animal feed, in animals consuming the feed, in the food produced from those animals, and from clinical cases). Due to the cost of WGS, this is likely to only be conducted for the purpose of research studies, or in the event that epidemiological or other evidence from outbreaks suggest that there may be reason to investigate these linkages further. Outbreak investigations currently work to identify the food source, but further traceback from there is more challenging and usually is not undertaken.

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# APPENDIX A: HAZARD AND FOOD

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## A.1 *SALMONELLA* GROWTH AND SURVIVAL

The following information is taken from a number of different sources but, unless otherwise referenced, is primarily derived from the *Non-typhoidal Salmonellae* data sheet prepared by ESR for MPI.<sup>76</sup> Content from the 2016 Risk Profile (Rivas et al. 2016) is also included.

### A.1.1 Growth

Temperature: Some evidence for growth at temperatures <7°C exists and 5.2°C has been reported as the minimum growth temperature, but this is serotype specific, the data are still not universally accepted and doubts surrounding the experimentation exist. Growth greatly reduced at <15°C. Maximum 49.5°C. Optimum 35-37°C.

pH: Minimum 3.8, optimum, 6.5-7.5, maximum 9.5. The minimum pH is influenced by other factors such as temperature, acid present, and the presence of salts and nitrate.

Atmosphere: Can grow in the presence or absence of air as a facultative anaerobe. *Salmonella* grows in inoculated raw minced beef and cooked crab meat (stored at 8-11°C) in the presence of 20-50% CO<sub>2</sub>. The growth rate on beef muscle stored at 20°C under nitrogen is only slightly less than that obtained when stored under air.

Water activity (a<sub>w</sub>): Minimum 0.94, optimum 0.99, maximum >0.99.

### A.1.2 Survival

*Salmonella* survives well in foods and on surfaces. Particularly in foods with low a<sub>w</sub>; for example, flour.

Temperature: *Salmonella* survive well in the environment, on foods, human skin and other substrates. Survival is longer at chilled, compared with ambient, temperatures but is dependent on other factors such as pH and a<sub>w</sub>. *Salmonella* can survive for long periods in frozen foods with a slow decrease in bacterial numbers due to cellular damage. Bacterial reduction is more rapid in the range 0 to 10°C than in the range -17 to -20°C. Some foods, including meat, ice cream and butter, appear to be protective of *Salmonella* during freezing and frozen storage. Rapid freezing promotes survival with lower frozen storage temperatures and less fluctuation giving greater survival (Jay et al. 2003).

Frozen storage temperatures near 0°C result in greater death or injury to bacterial cells.

pH: *Salmonella* are tolerant of acid conditions which is advantageous for survival in the environment and virulence.

Water activity (a<sub>w</sub>): Survival in dry environments is a characteristic of these organisms. Some serotypes can survive for months or years in foods with a low a<sub>w</sub> such as black pepper, chocolate, peanut butter and gelatine.

Biofilm production: Can form disinfectant and antibiotic-resistant biofilms which contribute to persistence in host, non-host and food-processing environments.

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<sup>76</sup> <https://www.mpi.govt.nz/dmsdocument/1214-Non-Typhoid-Salmonellae>; accessed 9 December 2022

Viable but Non-Culturable (VBNC) state: Can transition to the VBNC state after exposure to low temperatures (5°C) in nutrient-limiting microcosms for up to 300 days.

### A.1.3 Inactivation

Temperature: Inactivation is greater during the freezing process compared with subsequent frozen storage, but those cells that survive remain viable. Freezing does not ensure the inactivation of *Salmonella* in foods.

Most serotypes are killed by normal cooking conditions (core temperature of 75°C instantaneously or an equivalent time-temperature combination; for example, 70°C for 2 minutes). In microbiological terms “D” refers to a 90% (a decimal or 1 log<sub>10</sub> cycle) reduction in the number of viable organisms. D value temperature/time (°C/minutes) in “all meats” include: D<sub>60°C</sub> 12.2 minutes; D<sub>65°C</sub> 2.1 minutes and D<sub>70°C</sub> 0.4 minutes.

Some strains of some serotypes (for example, *S. Senftenberg*) are significantly more heat-tolerant than the others when tested in culture, and this is influenced by a<sub>w</sub>, solutes and pH of the culture medium.

D-values for *Salmonella* spp. can depend on the type of food involved. High fat and low moisture foods require more severe heat treatments to kill *Salmonella*; for example, in milk chocolate with <10% moisture, D<sub>80°C</sub> for *S. Typhimurium* in milk chocolate is 222 minutes.

pH: *Salmonella* dies outside the ranges of pH permitting growth (<3.8 and >9.5). Inactivation depends on factors including the type of acid present and the temperature with the rate of death decreasing as the temperature is reduced; for example, inactivation is more rapid in commercial mayonnaise at 20°C than it is at 4°C.

In the studies by Alford and Palumbo, the authors demonstrated how decreasing temperature increases the inhibitory effects of pH and NaCl. In broth, at 10°C, growth of 22/23 strains were inhibited by pH 5 and 2% NaCl (Alford and Palumbo 1969). At pH 5.8 (more representative of meat), 5% NaCl at 10°C was required to inhibit growth. Increasing the salt concentration slightly decreased survival time at 10°C.

Water activity (a<sub>w</sub>): At a<sub>w</sub> levels below those allowing growth (0.94), *Salmonella* dies slowly. The rate of death decreases as the a<sub>w</sub> is lowered and also decreases as the temperature is reduced (Troller and Christian 1978).

Radiation: D-values in foods are between 0.5 kGy and 0.8 kGy, with values higher in dried foods. Radiation sensitivity is influenced by the substrate, temperature and the presence or absence of oxygen. UV and heat treatment applied together provide a synergistic, simultaneous lethal effect for *S. Typhimurium* and *S. Enteritidis* in broth culture.

Sanitisers and disinfectants: Most disinfectants commonly used in the food industry, are effective against *Salmonella* at recommended user concentrations. Some disinfectants have a reduced effect against *Salmonella* on surfaces and in biofilms. Novel disinfectant strategies such as electrolysed water, antimicrobial materials and anti-biofilm-specific compounds have been shown to reduce or eliminate *Salmonella* under certain conditions.

Preservatives and other nonthermal processing technologies: *Salmonella* is sensitive to preservatives commonly used in foods. Growth is inhibited by benzoic, sorbic and propionic acid. Inhibition is enhanced by using a combination of factors; for example, the use of a preservative together with reduction in pH and temperature.

## A.2 PREVALENCE OF *SALMONELLA* IN ANIMAL FEED AND FOOD-PRODUCING ANIMALS IN NEW ZEALAND

### A.2.1 Prevalence and serotypes present in New Zealand animal feed

Data are collated from testing performed at the ESR ERL on non-human *Salmonella* isolations from poultry and animal feed.<sup>77</sup> Common serotypes of *Salmonella* isolated from animal feed over the time period 2011 to 2022 are presented in Table 8, and the results are described in Section 3.2.

A further data source for serotypes of *Salmonella* in poultry feed is annual data from the poultry industry, which is reported in the *Surveillance* biosecurity magazine published by MPI.<sup>78</sup> The data are received from poultry-testing laboratories and include poultry feed (finished and raw sources) testing, broiler samples, and environmental samples. There is some overlap between this data stream and the ESR ERL reporting; for example, both include data from the NMD programme. However, many isolates serotyped by poultry laboratories were not sent to ESR ERL for further typing, and thus not included in that surveillance reporting. Serotypes isolated from poultry feed and feed sources for the period 2011 to 2022 are presented in Table 9.

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<sup>77</sup> [https://surv.esr.cri.nz/enteric\\_reference/nonhuman\\_salmonella.php](https://surv.esr.cri.nz/enteric_reference/nonhuman_salmonella.php); accessed 3 October 2023

<sup>78</sup> <https://www.mpi.govt.nz/biosecurity/about-biosecurity-in-new-zealand/surveillance-biosecurity-magazine/>; accessed 2 October 2023

**Table 8. *Salmonella* serotypes identified 10 or more times from isolates submitted to the Enteric Reference Laboratory from non-poultry feed (A), poultry feed (P) and meat/bone meal (M) sources (2011-2022).<sup>1</sup>**

Serotype	2011			2012			2013			2014			2015			2016			2017			2018			2019			2020			2021			2022			Total
	A	P	M	A	P	M	A	P	M	A	P	M	A	P	M	A	P	M	A	P	M	A	P	M	A	P	M	A	P	M	A	P	M				
Infantis	6	8	14	3	3	42	3		37	1		12	1		1			9			13				1										154		
Agona		6	40		1	9		2	4			3	5		6			3					1		1			1	3						85		
Typhimurium	2	12		2	2	9			2	2	3		1	3	1	1	2		4	1	1		3			1		1			2				55		
Brandenburg		6	1			1					2	3			7		1	27			2				1				1						52		
Havana		1	11			6		1	7	2		9	1	1	4			1			1		1		1			2							49		
Mbandaka	1	2	5	7	3					1		5	1		3					3			1		3	2		2		6	3				48		
Anatum (includes var. 15+)	1	4			3	2			3			4		3				7			8		1		1	3		1						1	42		
Tennessee	1		16			13	2	1	2			3			2			2																	42		
Montevideo		2	2			6		1	21		1	2			3			1									1							1	41		
Senftenberg		1	1	1		2		5	4			10		2	1			1				2			2								1		33		
Derby		9	2			1											4		1	5			1												23		
Give (includes var. 15+)		1	5		3	1						5																				1			1	17	
Oranienburg					2	1	3	1						2											1											10	
<i>Total positive</i>	<i>11</i>	<i>85</i>	<i>100</i>	<i>13</i>	<i>37</i>	<i>100</i>	<i>9</i>	<i>13</i>	<i>81</i>	<i>10</i>	<i>8</i>	<i>57</i>	<i>13</i>	<i>13</i>	<i>29</i>	<i>2</i>	<i>6</i>	<i>56</i>	<i>5</i>	<i>2</i>	<i>36</i>	<i>2</i>	<i>11</i>	<i>5</i>	<i>0</i>	<i>12</i>	<i>8</i>	<i>0</i>	<i>4</i>	<i>19</i>	<i>0</i>	<i>10</i>	<i>3</i>	<i>1</i>	<i>6</i>	<i>2</i>	<i>769</i>

<sup>1</sup> Source: <https://www.esr.cri.nz/our-research/nga-kete/infectious-disease-intelligence/enteric-reference-testing/non-human-salmonella-isolates/>; accessed 3 October 2023

A: non-poultry feed, F: poultry feed, M: meat and bone meal

**Table 9. *Salmonella* serotypes identified 10 or more times from poultry laboratory data. Isolates were from poultry finished and raw feed sources; raw sources can also be used for feed for other species (2011 to 2022).<sup>1</sup>**

Serotype / Serogroup	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total (% of positives)
Mbandaka	4	6	2			1	81	5			16	8	123 (26.2)
Typhimurium	2	1	1		17	6	4			1	9		41 (8.7)
Infantis	6	10	9		6			2				2	35 (7.5)
Group C											31	3	34 (7.2)
Anatum (includes var 15+)	8	5	8		1		2		8				32 (6.8)
Havana	2								28				30 (6.4)
Agona	3	4				1			6	1	3	6	24 (5.1)
Fresno		10	9		3		1					1	24 (5.1)
Derby	4	1					11		2		1	1	20 (4.3)
Group E											15	3	18 (3.8)
Senftenberg	1		1		1		2		1		6		12 (2.6)
Rissen		1					1				9		11 (2.3)
<i>Total positive (% tested)</i>	<i>33 (0.9)</i>	<i>60 (2.6)</i>	<i>32 (2.3)</i>	<i>1 (0.1)</i>	<i>30 (0.8)</i>	<i>16 (0.4)</i>	<i>103 (3.2)</i>	<i>13 (0.5)</i>	<i>53 (1.4)</i>	<i>5 (0.2)</i>	<i>95 (1.3)</i>	<i>30 (0.3)</i>	<i>469 (1.0)</i>
<i>Total samples tested</i>	<i>3,528</i>	<i>2,336</i>	<i>1,417</i>	<i>1,538</i>	<i>3,578</i>	<i>4,150</i>	<i>3,232</i>	<i>2,877</i>	<i>3,699</i>	<i>2,632</i>	<i>7,250</i>	<i>9,201</i>	<i>45,438</i>

<sup>1</sup> Data were sourced from *Surveillance* magazine annual reports. <https://www.mpi.govt.nz/biosecurity/about-biosecurity-in-new-zealand/surveillance-biosecurity-magazine/>

### **A.2.2 *Salmonella* prevalence and serotypes in food-producing animals and meat**

Data are collated by ESR ERL from serotyping performed on non-human *Salmonella* isolations, which includes, but is not limited to, from the poultry environment and poultry miscellaneous samples including product, and livestock animals.<sup>79</sup> Based on the ESR ERL data, Table 10 shows the prevalence of *Salmonella* serotypes identified from food-producing animals mammalian livestock species (bovine, cervine, ovine, porcine and caprine) and poultry. The serotypes included in this table were selected based those listed in Table 8 and Table 9; the serotypes most often identified in feed samples. It should be noted that, like the feed data, the results in Table 10 come from samples collected for different purposes. This means that the prevalence data provide an indication of which serotypes are more common but are not true representations of actual prevalence of the top *Salmonella* serotypes from feed for 2011-2022 (based on data from Table 8 and Table 9). The animal isolates may arise from a range of different programmes and mechanisms, which include but are not limited to:

- Isolates and data from sick animals are collected via the MPI Biosecurity Surveillance & Incursion Investigation Team Animal health surveillance programme.
- Miscellaneous poultry isolates, including poultry product.
- Poultry and red meat samples collected via the NMD Programme.
- Isolates arising from project-specific work; for example research projects carried out by ESR on behalf of MPI.
- Animal isolates may be obtained from outbreak investigations.

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<sup>79</sup> [https://surv.esr.cri.nz/enteric\\_reference/nonhuman\\_salmonella.php](https://surv.esr.cri.nz/enteric_reference/nonhuman_salmonella.php); accessed 18 May 2022

**Table 10. Frequency of detection of common feed serotypes and *S. Enteritidis* from *Salmonella* isolations from food-producing mammalian (M) and poultry (P) species that were submitted to ESR's Enteric Reference Laboratory (2011 to 2022).<sup>1</sup>**

Serotype	2011		2012		2013		2014		2015		2016		2017		2018		2019		2020		2021		2022		Total	
	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	P <sup>2</sup>	M	P <sup>2</sup>	M	P
Typhimurium	540	39	305	9	222	20	143	23	173	14	166	11	279	10	207	19	247	12	269	15	204	38	157	37	2921	247
Brandenburg	88	3	59	0	105	0	105	1	79	0	88	1	122	0	95	0	111	0	77	0	65	0	15	1	1009	6
Give (includes var 15+)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	65	2	59	14	50	29	186	45
Infantis	28	19	12	10	11	9	2	9	4	2	0	0	7	2	2	1	0	1	0	1	1	14	2	11	69	79
Agona	11	11	1	12	6	27	4	6	6	4	4	1	12	0	13	1	3	2	1	0	3	4	6	7	70	75
Mbandaka	9	5	2	8	0	12	3	2	3	2	1	0	4	1	2	0	2	6	0	5	0	28	2	15	28	84
Senftenberg	17	2	4	0	2	1	0	5	2	2	2	0	5	1	3	2	2	2	1	1	4	2	7	10	49	28
Anatum (includes var 15+)	2	2	6	2	4	0	5	4	2	0	0	0	3	0	2	2	1	1	0	0	0	0	0	0	25	11
Havana	0	1	0	0	0	0	0	1	8	0	0	0	0	0	0	0	0	1	1	0	0	0	0	3	9	6
Oranienburg	0	0	5	0	3	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3	0	0	9	4
Fresno	3	0	2	4	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	6	7
Rissen	2	1	0	1	0	0	0	6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	9
Tennessee	2	0	2	0	1	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	6	3
Montevideo	0	0	1	2	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	8
Derby	1	1	1	1	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	5
<b>Total, feed serotypes</b>	<b>703</b>	<b>84</b>	<b>400</b>	<b>49</b>	<b>356</b>	<b>77</b>	<b>264</b>	<b>57</b>	<b>277</b>	<b>25</b>	<b>261</b>	<b>14</b>	<b>432</b>	<b>15</b>	<b>324</b>	<b>26</b>	<b>378</b>	<b>27</b>	<b>414</b>	<b>24</b>	<b>336</b>	<b>104</b>	<b>239</b>	<b>115</b>	<b>4384</b>	<b>617</b>
Enteritidis	5	0	7	0	6	0	2	10 <sup>3</sup>	6	0	9	0	9	0	4	0	3	0	3	0	3	177	1	97	58	284
<b>Total, all serotypes (%)</b>	<b>888</b> (79)	<b>98</b> (86)	<b>530</b> (75)	<b>78</b> (63)	<b>444</b> (80)	<b>94</b> (82)	<b>366</b> (72)	<b>78</b> (73)	<b>406</b> (68)	<b>33</b> (76)	<b>455</b> (57)	<b>19</b> (74)	<b>761</b> (57)	<b>21</b> (71)	<b>668</b> (49)	<b>34</b> (76)	<b>720</b> (53)	<b>40</b> (68)	<b>668</b> (62)	<b>40</b> (60)	<b>488</b> (69)	<b>344</b> (30)	<b>343</b> (70)	<b>230</b> (50)	<b>6737</b> (65)	<b>761</b> (81)

<sup>1</sup> Mammalian species include bovine, cervine, ovine, porcine and caprine. Poultry samples include environment and miscellaneous, including product samples. Data were sourced from: <https://www.esr.cri.nz/our-research/nga-kete/infectious-disease-intelligence/enteric-reference-testing/non-human-salmonella-isolates/>; accessed 4 October 2023.

<sup>2</sup> Higher numbers of isolates were received from poultry environmental samples in 2021 and 2022 than previous years due of increased testing as a consequence of the *S. Enteritidis* outbreak associated with poultry. *S. Enteritidis* is the only serotype which was required to be reported.

<sup>3</sup> Although the samples from which these isolates originated were tested in New Zealand, the samples were not believed to have originated in New Zealand.

The NMD Poultry Programme monitors *Salmonella* (and *Campylobacter*) contamination of poultry carcasses at the end of primary processing (Ministry for Primary Industries 2023a). Specifically, poultry tested includes a bird of any of the following species intended for human consumption:

- A chicken of the species *Gallus gallus* (both meat chickens and end-of-lay (EOL) chickens are tested);
- A duck of the species *Anas platyrhynchos domestica* or *Anas pekin* or *Cairina moschata*;
- A turkey of the species *Meleagris gallopavo*.

For standard throughput premises operators (>1,000,000 birds expected to be processed per season), three carcass rinsates are collected for ducks, EOLs, meat chickens and turkeys each processing day. For very low throughput poultry premises (<1,000,000 birds expected to be processed per season) three carcasses of each type of bird are collected on one processing day each processing week. Very low throughput poultry premises processing multiple poultry types are only required to sample three poultry carcasses per processing week. One carcass rinsate of the three sampled are tested for *Salmonella*. *Salmonella* isolates are sent to ESR ERL for further typing. Prevalence data on NMD programme testing of poultry for the years 2011 to 2022 are shown in Table 11 and serotype data are shown in Table 13.

**Table 11. *Salmonella* detections from National Microbiological Database (NMD) programme testing of poultry samples (2011 to 2022).**

Year	Meat chicken samples			Duck and turkey samples			End of Lay samples		
	Samples	Detections	% Detected	Samples	Detections	% Detected	Samples	Detections	% Detected
2011	2,040	5	0.25%	NR <sup>1</sup>	NR	NR	NR	NR	NR
2012	2,110	14	0.66%	NR	NR	NR	NR	NR	NR
2013	2,093	5	0.24%	NR	NR	NR	NR	NR	NR
2014	2,136	4	0.19%	NR	NR	NR	NR	NR	NR
2015	2,177	1	0.05%	NR	NR	NR	NR	NR	NR
2016	2,208	2	0.09%	45	0	0.00%	49	0	0.00%
2017	2,209	1	0.05%	253	2	0.79%	253	0	0.00%
2018	2,202	2	0.09%	253	4	1.58%	301	0	0.00%
2019	2,144	0	0.00%	255	3	1.18%	276	0	0.00%
2020	2,116	1	0.05%	191	2	1.05%	258	0	0.00%
2021	2,114	1 <sup>2</sup>	0.05%	179	2	1.12%	220	1	0.45%
2022	2,087	0	0.00%	177	3	1.69%	151	1	0.66%
<b>Total</b>	<b>25,636</b>	<b>36</b>	<b>0.14%</b>	<b>1353</b>	<b>16</b>	<b>1.18%</b>	<b>1,508</b>	<b>2</b>	<b>0.13%</b>

<sup>1</sup> NR; not reported

<sup>2</sup> This isolate was *S. Enteritidis*.

In addition to testing poultry, red meat intended for human consumption and arising from bovine, bobby calf, caprine and ratite sources, is also tested for *Salmonella* as part of the NMD testing programme. Seasonal sampling is required at the start of each season for standard throughput operators (who process more than 10,000 animals per season). Samples are collected (for fresh carcasses, wet/dry swabbing of specified sites) on one processing day in each processing week from a specified number of that product type. Sampling is required only until there are six consecutive clear processing weeks of samples (not detected) for each species and product type (fresh carcass, primal cuts, bulk meat) that season. Samples are composited for *Salmonella* testing and the results are reflective of the number of that product type sampled. *Salmonella* prevalence for NMD Programme testing of red meat is shown in Table 12 and serotypes isolated are shown in Table 13.

**Table 12. *Salmonella* detections from National Microbiological Database (NMD) Programme testing of red meat samples (2011 to 2022).**

Year	Bobby calf fresh carcass, bulk meat and primal cut samples			Bovine fresh carcass and bulk meat <sup>1</sup> samples			Caprine fresh carcass samples			Ratite fresh carcass samples		
	Samples	Detections	% Detected	Samples	Detections	% Detected	Samples	Detections	% Detected	Samples	Detections	% Detected
2011	3,860	22	0.57%	2,419	2	0.08%	427	1	0.23%	14	0	0.00%
2012	3,990	13	0.33%	1,290	0	0.00%	286	0	0.00%	8	0	0.00%
2013	4,003	14	0.35%	1,126	0	0.00%	325	1	0.31%	10	0	0.00%
2014	4,087	14	0.34%	1,013	0	0.00%	386	0	0.00%	14	0	0.00%
2015	3,900	16	0.41%	959	0	0.00%	387	0	0.00%	12	0	0.00%
2016	3,185	10	0.31%	951	1	0.11%	388	1	0.26%	20	0	0.00%
2017	2,975	18 (1) <sup>2</sup>	0.61%	925	1	0.11%	390	0	0.00%	60	0	0.00%
2018	2,875	11	0.38%	990	0	0.00%	370	0	0.00%	40	0	0.00%
2019	2,805	16	0.57%	980	0	0.00%	325	0	0.00%	35	0	0.00%
2020	2,425	12	0.49%	890	0	0.00%	290	0	0.00%	20	0	0.00%
2021	2,735	12 (1)	0.44%	1,075	0	0.00%	260	0	0.00%	40	0	0.00%
2022	2,500	9	0.36%	1,050	0	0.00%	185	0	0.00%	20	0	0.00%
<b>Total</b>	<b>39,340</b>	<b>167</b>	<b>0.42%</b>	<b>13,668</b>	<b>4</b>	<b>0.03%</b>	<b>4,019</b>	<b>3</b>	<b>0.07%</b>	<b>293</b>	<b>0</b>	<b>0.00%</b>

<sup>1</sup> Bovine bulk meat was only sampled in 2011.

<sup>2</sup> The number in brackets indicates the number of detections that were *S. Enteritidis*.

**Table 13. *Salmonella* serotypes of isolates from National Microbiological Database (NMD) Programme testing of poultry and red meat samples (2011 to 2022).**

Serotype	Chicken (meat)	Chicken (EOL)	Duck and turkey	Bovine (bobby calf)	Bovine (fresh carcass / bulk meat)	Caprine	Total
Agona	1 (3%)			8 (5%)			9 (4%)
Anatum			2 (13%)	2 (1%)		1 (33%)	5 (2%)
Bovismorbificans	4 (11%)			14 (8%)			18 (8%)
Brandenburg		1 (50%)		65 (39%)			66 (29%)
Derby	1 (3%)		2 (13%)	1 (1%)			4 (2%)
Emek				8 (5%)	2 (40%)		10 (4%)
<i>S. enterica</i> subsp. <i>enterica</i> ser.47:z4,z23				2 (1%)			2 (1%)
Enteritidis	1 (3%)			2 (1%)			3 (1%)
Give				9 (5%)			9 (4%)
Group O	1 (3%)		3 (19%)				4 (2%)
Havana					1 (20%)		1 (0.4%)
Hindmarsh				4 (2%)			4 (2%)
Infantis	8 (22%)		3 (19%)	5 (3%)	1 (20%)		17 (7%)
Kottbus				1 (1%)			1 (0.4%)
Lexington (includes var 15+)			1 (6%)	2 (1%)			3 (1%)
Mbandaka	7 (19%)						7 (3%)
Meleagridis						2 (67%)	2 (1%)
Saintpaul				1 (1%)			1 (0.4%)
Senftenberg		1 (50%)					1 (0.4%)
Typhimurium	6 (17%)		5 (31%)	42 (25%)			53 (23%)
Thompson	6 (17%)						6 (3%)
<b>Total</b>	<b>36</b>	<b>2</b>	<b>16</b>	<b>167</b>	<b>5</b>	<b>3</b>	<b>229</b>

<sup>1</sup> Percentages may not add up to 100% as serotypes were not provided for all isolates; *S. Menston* was also excluded as this may have been the laboratory control strain.

### **A.3 OVERSEAS DATA: *SALMONELLA* IN ANIMAL FEED AND FEED COMPONENTS**

#### **A.3.1 Prevalence of *Salmonella* in animal feed and feed components**

##### **Surveys reported in the scientific literature**

Table 14 summarises information on *Salmonella* in animal feed and feed components published in the scientific literature during the period 2011-2023. Table 15 summarises results from surveys of the feed mill environment.

**Table 14. Prevalence of *Salmonella* in animal feed and feed components (published in the scientific literature since 2011).**

Year	Country/region	Samples tested	Number positive/total (%)	Top <i>Salmonella</i> serotype/s (isolations or %)	Reference
2003-2018	Australia	Finished feed Blood meal Fishmeal Meat and bone meal Poultry offal meal Canola meal Cottonseed meal Soybean meal Sunflower meal Whole grain Other plant-based raw materials	89/3822 (2.3) 8/278 (2.9) 37/84 (44.0) 216/1214 (17.8) 3/39 (7.7) 221/1246 (17.7) 13/97 (13.4) 56/1257 (4.5) 9/66 (13.6) 10/575 (1.7) 6/76 (7.9)	Agona (111), Tennessee (75), Senftenberg (64), Mbandaka (52), Orion (49), Anatum (41)	(Parker et al. 2019)
1998-2011	Austria	<i>Compound feed</i> Pigs, cattle Poultry <i>Feed materials</i> Fishmeal and bone meal Oilseed meal, cereals	5/485 (1.0) 33/2297 (1.4) 20/207 (9.7) 53/1086 (4.9)	NS	(Reiter et al. 2012)
NS	Brazil	Soybeans for processing Soybean meal	8/495 (1.6) 14/88 (15.9)	Mbandaka, Cubana, Agona, Infantis	(Rocha et al. 2022)
NS	Brazil	Bagged ingredients Bulk ingredients Finished feed	0/60 (0) 16/384 (4.2) 2/80 (2.5)	Montevideo, Senftenberg, Agona, Anatum, Cerro, Orion, Schwarzengrund, Tennessee, O:3,10	(Pellegrini et al. 2015)
2009-2014	Costa Rica	Poultry feed Meat and bone meal Other feeds	76/1420 (5.4) 23/86 (26.7) 8/129 (6.2)	Havana (15), Rissen (14), Give (12), Schwarzengrund (10), Soerenga (10)	(Molina et al. 2015)
2017-2018	Ethiopia	Poultry feed (on-farm)	0/59 (0)	ND	(Dagnew et al. 2020)
2021	Great Britain (regulatory testing)	Compound ruminant feed Compound pig feed Compound poultry feed Compound feed (other species) Feed ingredients or other products <i>Total feed and ingredients</i>	20 <sup>1</sup> 21 24 27 743 835	Rissen (118), Tennessee (55), Typhimurium (51)	(Animal and Plant Health Agency 2022)
2020		Compound ruminant feed Compound pig feed Compound poultry feed Compound feed (other species) Feed ingredients or other products <i>Total feed and ingredients</i>	19 9 37 20 672 757	Tennessee (82), Rissen (62), Kedougou (40)	(Animal and Plant Health Agency 2021)
2019		Compound ruminant feed Compound pig feed Compound poultry feed Compound feed (other species) Feed ingredients or other products <i>Total feed and ingredients</i>	10 4 48 29 622 713	Tennessee (60), Senftenberg (47), Ohio (42)	(Animal and Plant Health Agency 2020)
2012-2013	Ireland	Feed ingredients	2/338 (0.6, wheat and soybean meal)	4,12:i:-	(Burns et al. 2015)

Year	Country/ region	Samples tested	Number positive/total (%)	Top <i>Salmonella</i> serotype/s (isolations or %)	Reference
		Compound feed	3/317 (1.0, finisher meal, dry sow meal, dry sow pellets)		
2019	Kenya	<i>Poultry feed:</i> Layer mash Growers mash Starter mash Finisher mash Kienyeji mash Chick mash Other	11/29 (38) 10/27 (37) 5/27 (19) 1/6 (17) 5/27 (19) 9/30 (30) 1/4 (25)	NS	(Ngai et al. 2021)
NS	Nigeria	Broiler feed	6/16 (37.5)	NS	(Mohammed et al. 2021)
2012	Norway	Dust from raw soybeans Soybean meal (end product)	36/312 (11.5) 0/2690 (0)	Senftenberg, Mbandaka, Cerro, Agona, Tennessee (includes mill isolates)	(Wierup and Kristoffersen 2014)
2007	Poland	Rapeseed derived Sunflower seed derived Soybean derived Poultry meal Meat and bone meal Fishmeal Maize Barley Oats Wheat	1/22 (4.6) 15/1315 (1.1) 7/72 (9.7) 0/4 (0) 0/219 (0) 1/218 (0.5) 0/3 (0) 0/7 (0) 0/3 (0) 0/12 (0)	NS	(Kukier and Kwiatek 2011)
2008	Poland	Rapeseed derived Sunflower seed derived Soybean derived Poultry meal Meat and bone meal Fishmeal Maize Barley Oats Wheat	3/90 (3.3) 3/485 (0.6) 3/42 (7.1) 0/2 (0) 3/257 (1.2) 1/287 (0.4) 0/23 (0) 0/13 (0) 0/14 (0) 0/57 (0)	NS	(Kukier and Kwiatek 2011)
2009	Poland	Rapeseed derived Sunflower seed derived Soybean derived Poultry meal Meat and bone meal Fishmeal Maize Barley Oats Wheat	7/208 (3.4) 0/370 (0) 7/299 (2.3) 0/245 (0) 7/801 (0.9) 0/532 (0) 0/31 (0) 1/16 (6.3) 0/5 (0) 0/87 (0)	NS	(Kukier and Kwiatek 2011)
2010	Poland	Rapeseed derived Sunflower seed derived Soybean derived Poultry meal Meat and bone meal Fishmeal Maize	4/202 (2.0) 0/252 (0) 17/312 (5.5) 0/465 (0) 0/994 (0) 8/402 (2.0) 0/28 (0)	NS	(Kukier and Kwiatek 2011)

Year	Country/ region	Samples tested	Number positive/total (%)	Top <i>Salmonella</i> serotype/s (isolations or %)	Reference
		Barley Oats Wheat	0/15 (0) 0/7 (0) 0/106 (0)		
2007- 2008	Spain	Soybean meal Barley Sunflower meal Fish meal Corn Wheat bran Cotton seeds Wheat flour Other <i>Total feed ingredients</i>	26 <sup>2</sup> /497 (5.2) 1/177 (0.6) 2/35 (5.7) 2/24 (8.3) 1/247 (0.4) 6/147 (4.1) 10/58 (17.2) 2/86 (2.3) 5/288 (1.7) 55/1,559 (3.5)	Senftenberg (13.7%)	(Torres et al. 2011)
		Pelleted compound feed Non-pelleted compound feed	3/476 (0.6) 51/1,182 (4.3)	Anatum (8.5%), Mbandaka (8.5%)	
NS	Turkey	Finished layer feed	4/24 (16.7)	Typhimurium (100%)	(Gunaydin et al. 2021)
2009	US (Texas)	Cattle feed	16/191 (8.4)	Tennessee, Mbandaka, Montevideo, Rough:gms:-	(Carlson et al. 2011)
2002- 2003	US	Animal feed ingredients <i>Animal byproducts</i> Meat and bone meal Poultry meal Blood meal Feather meal Fish meal Bone meal	28/72 (38.9) 3/17 (17.6) 5/16 (31.3) 1/10 (10.0) 4/5 (80.0) 1/2 (50.0)	Tennessee, Cerro, Montevideo, Oranienburg	(Ge et al. 2013)
		<i>Plant byproducts</i> Lucerne meal Oilseed byproducts Soybean meal Cottonseed meal Sunflower meal Linseed meal Canola meal Corn products Corn gluten Corn meal Corn germ Hominy	0/13 (0.0) 4/49 (8.2) 3/31 (9.7) 1/8 (12.5) 0/5 (0.0) 0/3 (0.0) 0/2 (0.0) 0/17 (0.0) 0/10 (0.0) 0/5 (0.0) 0/1 (0.0) 0/1 (0.0)		
2007- 2009	US	Pig feed	10/275 (3.6)	NS	(Molla et al. 2010)
2002- 2006	US	Complete feeds Feed ingredients	34/363 (9.4) 104/337 (30.9)	Senftenberg (8.9%), Montevideo (8.9%),	(Li et al. 2012)
2007- 2009		Complete feeds Feed ingredients	10/180 (5.6) 40/206 (19.4)	Mbandaka (8.6%), Tennessee (6.2%)	

Year	Country/ region	Samples tested	Number positive/total (%)	Top <i>Salmonella</i> serotype/s (isolations or %)	Reference
2007- 2011	US (Texas)	<i>Ready-to-eat feed:</i>			(Hsieh et al. 2016)
		Dry beef cattle	51/259 (20)	Mbandaka (52), Montevideo (33), Senftenberg (22), Livingstone (19), Infantis (18), Anatum (17), Cerro (11), Meleagridis (11), Orion (11), Liverpool (10), Tennessee (10)	
		Medicated beef cattle	13/93 (14)		
		Dairy cattle	12/159 (8)		
		Medicated dairy cattle	0/11 (0)		
		Medicated poultry	1/7 (14)		
		Sheep and goat	2/13 (6)		
		Medicated sheep and goat	10/33 (30)		
		Swine	0/17 (0)		
		Medicated swine	0/6 (0)		
		<i>By-products:</i>			
		Alfalfa	1/17 (6)		
		Animal protein	122/254 (48)		
		Barley	0/5 (0)		
		Brewer's/distiller's products	4/135 (3)		
		Corn	7/295 (2)		
		Cottonseed	53/245 (22)		
		Fats and oils	0/4 (0)		
		Fishmeal	16/19 (84)		
		Grain sorghum	1/43 (2)		
		Peanut	4/12 (33)		
		Poultry	2/40 (5)		
		Rice	25/99 (25)		
		Minerals	2/8 (25)		
Medicated minerals	0/2 (0)				
Misc. animal products	0/168 (0)				
Misc. ingredients	14/249 (6)				
Oats	0/7 (0)				
Screenings	1/7 (14)				
Soybeans	16/136 (12)				
Wheat	3/114 (3)				
NS	US (Alabama)	Corn meal	0/40 (0)	ND	(Munoz et al. 2021)
		Soybean meal	0/40 (0)		
		DDGS	0/20 (0)		
		Poultry meal	0/16 (0)		
		Corn gluten meal	0/8 (0)		
		Peanut meal	0/4 (0)		
		Wheat	0/4 (0)		
		Mixed feeds	0/160 (0)		
2018	US	Animal feeds obtained from feed mills	19/222 (8.6)	Infantis (10), Heidelberg (3)	(Shariat et al. 2021)
2010	US and Canada	Poultry meal	12	Montevideo (13%), Senftenberg (11%), Mbandaka (7%), Orion (7%), Livingstone (6%), Tennessee (4%), Infantis (4%), Cerro (4%), group C1 (4%)	(Jiang 2016)
		Pork and beef crax	20		
		Meat meal	12		
		Meat and bone meal	33		
		Feather meal	4		
		Blood meal	1		
		Fish meal	1		
2019	Viet Nam	Pig feed	5/123 (4.1)	Weltevreden	(Minh et al. 2020)

Abbreviations: NS, not serotyped; ND, not detected.

<sup>1</sup> The number of samples tested for each category was not provided for data collated by APHA.

<sup>2</sup> The number of positive samples was calculated from N and the percent positive.

**Table 15. Prevalence of *Salmonella* in the animal feed mill environment (published in the scientific literature since 2011).**

Year	Country/region	Samples tested	Number positive/total (%)	Top <i>Salmonella</i> serotype/s (isolations or %)	Reference
2003-2018	Australia	<i>Surface swabs:</i> Intake pit and augur Mixer Conditioner Press Cooler Coater Outload Other	39/1054 (3.7) 11/1259 (0.9) 10/1440 (0.7) 71/3803 (1.9) 186/3679 (5.1) 9/182 (4.9) 59/3493 (1.7) 16/299 (5.4)	Anatum (115), Mbandaka (58), Senftenberg (53), Tennessee (27), ssp I ser4,12:D (26)	(Parker et al. 2019)
NS	Brazil	Soybean mill environmental (dust) samples	70/148 (47.3)	Mbandaka, Cubana, Agona	(Rocha et al. 2022)
NS	Brazil	<i>Debris/dust:</i> Conveyors Scale Grinder Mixer Extruder Pellet mill/cooler Dust on floor Debris	20/164 (12.2) 1/44 (2.3) 1/37 (2.7) 3/45 (6.7) 0/24 (0) 2/80 (2.5) 12/124 (9.7) 8/210 (3.8)	Montevideo, Orion, Mbandaka, Tennessee	(Pellegrini et al. 2015)
2021	Great Britain	Feed mill environment (regulatory testing)	115 <sup>1</sup>	Kedougou (33), Ohio (27), Senftenberg (11)	(Animal and Plant Health Agency 2022)
2020			138	Kedougou (26), Ohio (26), Tennessee (11)	
2019			123	Kedougou (21), Ohio (25), Senftenberg (16)	
2016-2019	UK	Broiler feed mills – dust and gauze swab samples	907/12,791 (7.1)	Kedougou (29), 13,23:i:- (21)	(Gosling et al. 2022)
2018-2021	Japan	Feed storage facility – deposits, adhering material and environmental swabs	24/472 (5.1)	Anatum, Minnesota	(Morita et al. 2022)
2012	Norway	<i>Soybean mill environment</i> Outdoor environment Indoor “clean zone” Indoor “dirty zone”	13/61 (21.3) 3/778 (0.4) 21/228 (9.2)	Senftenberg, Mbandaka, Cerro, Agona, Tennessee (includes raw soybean dust isolates)	(Wierup and Kristoffersen 2014)
2007-2008	Spain	<i>Dust samples</i> Cooler Collectors Gridding Elevators Intake pit Storage bin for final product Pellet press Mill Corridors Packaging Mixer	7 <sup>2</sup> /131 (5.3) 8/83 (9.6) 1/10 (10.0) 2/7 (28.6) 34/128 (26.6) 4/43 (9.9) 0/6 (0.0) 10/73 (13.7) 4/43 (9.3) 0/15 (0.0) 2/43 (4.6)	Anatum (10.7%), Mbandaka (7.1%),	(Torres et al. 2011)

Year	Country/ region	Samples tested	Number positive/total (%)	Top <i>Salmonella</i> serotype/s (isolations or %)	Reference
		Scales <i>Total dust</i>	1/12 (8.3) 73/594 (12.3)		
2016	US	Pig feed mills – dust, swabs and finished feed	Culture ( <i>Salmonella</i> spp.) 157/237 (66.2) PCR ( <i>S. enterica</i> ) 31/157 (19.7)	NS	(Magossi et al. 2019)
2018-2019	US	Pig feed mills - swabs	19/405 (4.7)	NS	(Magossi et al. 2020)

<sup>1</sup> The number of samples tested was not provided for data collated by APHA.

<sup>2</sup> The number of positive samples was our best estimate based on the reported N and the percent positive.

In the study of Gosling et al. (2022) considerable variation was found between *Salmonella* prevalence in the 22 feed mills investigated and between different visits to the same feed mill. Overall feed mill prevalence was in the range 0.0 to 36.2%. Some feed mills showed evidence of persistent strains, while for other feed mills the distribution of strains was inconsistent between different visits.

For most studies, only prevalence was reported. Jiang et al. (2016) also reported numbers of *Salmonella* in rendered product. The mean MPN/g ranged from <0.03 (from crax) to 240 (from blood meal).

### Great Britain

Data on the detection of *Salmonella* in animal feed tested under the Department for Environment Food & Rural Affairs (DEFRA) and Animal By-Products Regulations (Appendix C.2) is collated yearly by the Animal and Plant Health Agency (APHA) (Animal and Plant Health Agency 2022). Specifically, individual data are available for *Salmonella* detections in compound feeds (for ruminants, pigs, poultry, and unspecified), ingredients and the feed mill environment. The data for the last three years for which data were available (2019-2021) are shown in Table 14 and Table 15. There were 835 total isolations of *Salmonella* in 2021, including 92 isolations from compound feeds and 743 from feed ingredients. This is an increase of 10.3% compared with 2020 (757 isolations), and of 17.1% compared with 2019 (713 isolations). However, due to the absence of information about the number of samples tested, caution should be taken when comparing data from year-to-year. For feed ingredients, the highest number of isolations in 2021 was from rapeseed (73 isolations), followed by mixed oil seeds (69 isolations), soya bean meal (38 isolations) and poultry offal meal (15 isolations) (Animal and Plant Health Agency 2022). Similar trends were also observed in previous years (Animal and Plant Health Agency 2021). There were fewer *Salmonella* isolations from feed mill environments in 2021 (115) compared with 138 from 2020 and 123 from 2019.

### European Union

In 2021, overall EU-level occurrence of *Salmonella*-positive samples in any 'animal and vegetable-derived feed' was 0.55% ( $n = 71,965$ ) (European Food Safety Authority and European Centre for Disease Prevention and Control 2022). In compound feed (finished feed for animals), the prevalence of *Salmonella*-positive units was 0.40% ( $n = 15,463$ ) for poultry feed, 0.58% for cattle feed ( $n = 2,909$ ) and 0.36% for pig feed ( $n = 4,123$ ).

The European Commission's Rapid Alert System for Food and Feed<sup>80</sup> contains approximately 260 notifications for pathogenic microbial hazards in animal feed and feed components (since 2020). All but one of the notifications relate to the detection of *Salmonella*. Materials most frequently notified are soybean products ( $n = 62$ ), rapeseed products ( $n = 49$ ), animal protein products ( $n = 36$ ) and fishmeal ( $n = 29$ ). While *Salmonella* serotypes are only reported for 114 notifications, the most frequently reported serotypes are *S. Senftenberg* ( $n = 25$ ), *S. Agona* ( $n = 18$ ) and *S. Typhimurium* ( $n = 7$ ).

### A.3.2 Serotypes in animal feed and feed ingredients

Common *Salmonella* serotypes isolated from feed product, feed ingredients and feed mills from individual studies are listed in Table 14 and Table 15. The most prevalent serotype depended on the sample type, study and region.

For Great Britain testing of animal feed, ingredients and the feed mill environment, data are collated for all *Salmonella* serotypes. *S. Tennessee* was amongst the most common serotype for all feed categories for 2019 to 2021 (Animal and Plant Health Agency 2022). *S. Rissen*, *S. Kedougou*, *S. Senftenberg*, *S. Ohio* and/or *S. Typhimurium* rounded out the top three serotypes for each year (Animal and Plant Health Agency 2022). The majority of *S. Kedougou* and *S. Ohio* isolates were from feed mills, and were reported to likely indicate resident contamination of some feed mills. *S. Senftenberg* was another common serotype of feed mills.

Regulated serotypes that are considered to be of special public health importance in Great Britain under the DEFRA Codes of Practice, 2021 (Appendix C.2) are also reported for each category. In 2021, the number of regulated serotypes isolations increased by 15.9% in 2021 compared with 2020 (124 isolations versus 107 isolations) and by 40.9% compared with 2019 (88 isolations). In 2021, there were 51 isolations of *S. Typhimurium*, 40 of *S. Infantis*, 13 of *Salmonella* 4,12:i:-, 11 of *Salmonella* 4,5,12:i:-, six of *S. Enteritidis* and three of *S. Hadar*. The number of samples tested is not known but these data show *S. Typhimurium* and *S. Infantis* to be relatively common.

A specific analytical method (CRISPR) was used to determine the relative abundance of *Salmonella* serotypes in 50 *Salmonella*-positive feed samples, including 25 feed ingredients, 13 finished feeds and 12 feed mill dust samples (Shariat et al. 2022). Over half of the samples contained two or more serotypes, with the maximum being 11 serotypes in one sample. Serotypes commonly detected as the major type (>50% relative abundance) were Mbandaka (11), Senftenberg (7), Havana (5), Anatum (5), Reading (4) and Enteritidis (4).

A scoping review of 547 studies concerning *Salmonella* and animal feed listed the serotypes most frequently reported from 106 studies of feed processing plants (Sargeant et al. 2021). *S. Senftenberg* and *S. Typhimurium* were most commonly reported (37 studies), followed by *S. Agona* (30), *S. Mbandaka* (30), *S. Montevideo* (26), *S. Infantis* (25), *S. Enteritidis* (23), *S. Anatum* (20), *S. Schwarzengrund* (18), *S. Livingstone* (16), and *S. Tennessee* (16). Note that for some studies, the serotype/s reported may have been influenced by the study purpose, such as outbreak investigations for a particular serotype.

A systematic review and meta-analysis was carried out of 97 studies published over the period 1959 to 2019, reporting serotypes on *Salmonella* detected in finished feed, feed ingredients and the feed mill equipment and environment (Parker et al. 2022a). Results of the meta-analysis are summarised in Table 16. *S. Mbandaka*, *S. Senftenberg* and *S. Tennessee* were

<sup>80</sup> [https://food.ec.europa.eu/safety/rasff\\_en](https://food.ec.europa.eu/safety/rasff_en); accessed 23 May 2023

the most commonly reported serotypes from finished feed and feed ingredients, while *S. Senftenberg*, *S. Anatum* and *S. Mbandaka* were the most common from the feed mill environment.

**Table 16. Most frequently reported *Salmonella* serotypes in finished animal feed, animal feed ingredients and animal feed mill equipment and environment, by WHO region. Data from Parker et al. (2022a).<sup>1</sup>**

Serotype	Isolates (number of studies)	Region (studies)					
		Europe (21)	Americas (29)	Western Pacific (10)	Eastern Mediterranean (4)	South-east Asia (4)	Africa (4)
<b>Frequency in finished feed</b>							
Senftenberg	817 (11)	747	43	27	0	0	0
Mbandaka	593 (11)	485	26	9	0	0	73
Tennessee	567 (13)	534	10	23	0	0	0
Salford	458 (1)	0	0	0	0	0	458
Agona	386 (9)	375	6	5	0	0	0
Typhimurium	276 (14)	165	18	36	0	31	26
Montevideo	238 (11)	122	76	3	0	0	37
Schwarzengrund	225 (5)	0	5	0	0	0	220
Binza	164 (2)	161	0	3	0	0	0
Infantis	161 (14)	63	13	14	0	0	71
<b>Frequency in feed ingredients</b>							
Mbandaka	1570 (16)	1461	62	44	0	2	1
Tennessee	1428 (27)	1197	90	133	5	3	0
Senftenberg	1097 (37)	810	172	104	4	7	0
Agona	827 (17)	672	22	130	0	3	0
Anatum	383 (25)	216	86	62	3	14	2
Montevideo	372 (28)	204	153	7	6	2	0
Typhimurium	328 (23)	285	8	25	5	2	3
Binza	313 (12)	212	99	0	2	0	0
Infantis	309 (25)	204	54	47	0	1	3
Havana	213 (12)	134	10	63	2	4	0
<b>Frequency on feed mill equipment and in the feed mill environment</b>							
Senftenberg	151 (9)	87	11	53	-	-	-
Anatum	150 (7)	28	7	115	-	-	-
Mbandaka	138 (9)	64	16	58	-	-	-
Agona	121 (9)	101	19	1	-	-	-
Livingstone	75 (5)	75	0	0	-	-	-
Typhimurium	63 (7)	61	2	0	-	-	-
Tennessee	57 (6)	26	4	27	-	-	-
Kedougou	54 (3)	54	0	0	-	-	-
Montevideo	52 (8)	40	12	0	-	-	-
Cubana	50 (7)	42	6	2	-	-	-

<sup>1</sup> There are minor differences between the published data and the data presented here; updated data were provided by the study lead author and have been included here with their consent (Elizabeth Parker, Ohio State University, pers. comm., 3 October 2023).

### A.3.3 Antimicrobial resistance in animal feed, feed components and feed mills

Various studies have investigated the antimicrobial resistance of *Salmonella* from animal feed, feed components and feed mill environments. A systematic review of 21 studies estimated the prevalence of antimicrobial resistant *Salmonella* arising from compound animal feed and feed ingredients (Parker et al. 2022a). Studies assessed determined antimicrobial resistance by

either a conventional phenotypic approach or *in silico* analysis of isolate genomes. The antibiotics to which the highest proportions of *Salmonella* isolates were included amikacin (88/431; 20%), tetracycline (~305/1735;<sup>81</sup> 18%), streptomycin (256/1497; 17%), cefotaxime (18/128; 14%) and sulfisoxazole (76/672; 11%). The review noted that although it was difficult to compare regions because of the varying number of isolates tested, Africa (313 isolates) and Southeast Asia (34 isolates) had a larger proportion of antimicrobial resistant isolates than other regions. Data from individual studies included in the systematic review were not detailed further in this report.

One study investigated the antimicrobial resistance of *Salmonella* isolates collected from raw feed components, equipment and finished feed from 17 commercial feed mills in Australia, between 2012 and 2021 (Parker et al. 2022b). Of the 453 isolates tested, 356 (79%) were susceptible to all antimicrobials tested, 49 (11%) were resistant to streptomycin only, and 48 (11%) were resistant to two or more antimicrobials. A majority of the 48 antimicrobial resistant isolates arose from the post-heat treatment feed milling equipment (44/124 isolates; 35%) and there were two isolates each from raw ingredients (2/228 isolates; 1%) and finished feed (2/101 isolates; 2%). Antimicrobial resistant isolates were significantly more likely to be detected from the feed mill equipment compared with finished feed ( $p < 0.001$ ) and raw ingredients ( $p = 0.006$ ). The most commonly identified serotypes amongst the antimicrobial resistant isolates were *S. Anatum* (16 isolates); *S. Mbandaka* (16 isolates) and *S. Singapore* (11 isolates).

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<sup>81</sup> The number of isolates resistant to tetracycline was estimated based on the proportion resistant and number of isolates.

# APPENDIX B: EVALUATION OF ADVERSE HEALTH EFFECTS

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## B.1 DISEASE CHARACTERISTICS FOR HUMANS

The following information was obtained from the *Non-typhoidal Salmonellae* datasheet.<sup>82</sup>

Incubation: 6-72 hours, commonly 12-36 hours.

Condition: Salmonellosis, or more generally gastroenteritis or enterocolitis.

Symptoms: Self-limiting watery diarrhoea, abdominal cramping, vomiting, nausea, fever and headache. Symptoms typically last between 2-7 days.

Long Term Effects: Bacteraemia and focal systemic infections can result in up to 5% of cases. Major risk factors for invasive disease are co-infection with HIV, malaria and malnutrition. Reactive arthritis and Reiter's syndrome may develop in a small percentage of patients 3-4 weeks after enteritis. Excretion of *Salmonella* can occur for up to seven weeks after infection.

Toxins: Toxins are not produced in foods.

At risk groups: Anyone can be infected, but the young, elderly, immunocompromised and those with underlying disease are particularly at risk. The highest incidence is reported for infants <1 year and children aged 1-4 years. Risk factors include consumption of food at retail premises, travelling abroad and contact with farm animals.

Treatment: The infection is usually self-limiting and treatment is rarely required. Uncomplicated gastroenteritis may require supportive therapy such as fluid and electrolyte replacement, especially in the elderly or young children. However, when necessary, fluoroquinolones are the antibiotic of choice. Azithromycin is a relatively new antibiotic used for multi-drug-resistant isolates.

## B.2 DOSE-RESPONSE

As discussed in the 2011 Risk Profile (Cressey et al. 2011), the ability of *Salmonella* to cause illness, as reflected in its dose-response, depends on the serotype, host susceptibilities, the food matrix and the dose. The dose-response is the relationship between the number of microorganisms ingested and the probability of a specific outcome such as infection, illness or death (Bollaerts et al. 2008). Ascertaining dose-response is very challenging as it relies on data from reported outbreaks where both the human health outcomes and number of pathogenic microorganisms ingested were known, human trials (which are ethically difficult and usually involve healthy humans and not vulnerable host populations) and/or extrapolation from animal trials. The dose-response data for *Salmonella* currently rely on outbreak data and human trials. Modelling approaches attempt to account for known sources of error and variability.

A study assessed *Salmonella* dose-response using data from 35 salmonellosis outbreaks, three sporadic cases for which there was good dose information and two human volunteer feeding studies (Teunis et al. 2010). The study estimated that the number of cells that need to be ingested to cause a 50% probability of illness was as low as 36.3, although the 95%

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<sup>82</sup> <https://www.mpi.govt.nz/dmsdocument/1214-Non-Typhoid-Salmonellae>; accessed 9 December 2022

percentiles were wide (0.69-1.26 x 10<sup>7</sup> cells). However, there were a number of shortcomings in this study; for example, how the unknown susceptibility status of the hosts were handled.

A more recent assessment attempted to address the limitations present in the Teunis et al. (2010) study. The study combined data from six human studies and 44 outbreaks to determine the infectivity and pathogenicity of several *Salmonella* serotypes (Teunis 2022). The study was not restricted to particular serotypes of *Salmonella*, but had a stronger focus on the two most common causing disease; *S. Typhimurium* and *S. Enteritidis*. The models estimated that *S. Enteritidis* was three to four times more infectious than *S. Typhimurium*, and three to four times more pathogenic, at low doses. However, there was more variation in pathogenicity for *S. Enteritidis* than *S. Typhimurium*.

“Infection” refers to the presence of elevated numbers of reproducing pathogens in the intestinal tract, which does not necessarily result in illness symptoms. Specifically, the model from Teunis (2022) estimated that the median dose required for 50% probability of infection by *S. Enteritidis* was very low at 1.82 x 10<sup>0</sup> cells (95% range of 7.25 x 10<sup>-1</sup> to 3.45 x 10<sup>2</sup> cells). This value was 1.78 x 10<sup>1</sup> cells for *S. Typhimurium* (95% range of 9.07 x 10<sup>-1</sup> to 5.85 x 10<sup>2</sup> cells). Data for infectivity of 11 other serotypes was more limited, which resulted in a wider range in instance in estimate uncertainty. The dose required for 50% probability of infection ranged from 2.16 x 10<sup>0</sup> cells for *S. Heidelberg* (95% range of 6.93 x 10<sup>-1</sup> to 1.45 x 10<sup>2</sup> cells), to 6.53 x 10<sup>3</sup> cells for *S. Derby* (95% range of 1.31 x 10<sup>0</sup> to 8.05 x 10<sup>9</sup> cells).

“Illness” refers to when intestinal microorganisms engage in damaging activities resulting in illness symptoms, and the dose required to cause illness is often higher than the dose required to cause infection. Pathogenicity is defined as the potential for causing illness in a host. The median dose required for a 1% probability of illness was 9.89 x 10<sup>0</sup> cells for *S. Typhimurium* (95% range of 3.23 x 10<sup>-1</sup> to 5.72 x 10<sup>1</sup> cells) and 6.14 x 10<sup>-1</sup> cells for *S. Enteritidis* (95% range of 2.43 x 10<sup>-1</sup> to 1.94 x 10<sup>0</sup> cells). The median dose required for 50% probability of illness was 1.50 x 10<sup>3</sup> cells for *S. Typhimurium* (95% range of 3.81 x 10<sup>1</sup> to 8.81 x 10<sup>7</sup> cells) and 3.36 x 10<sup>3</sup> cells for *S. Enteritidis* (95% range of 1.82 x 10<sup>1</sup> to 3.18 x 10<sup>9</sup> cells).

The probability of infection also depends on other factors such as food type; for example, *Salmonella* in foods with a high fat content, and foods from outbreaks associated with eggs high in fat content appear to be more likely to improve opportunity for infection (Teunis 2022).<sup>83</sup>

### **B.3 SALMONELLOSIS TESTING AND TYPING IN NEW ZEALAND**

Salmonellosis is a notifiable disease in New Zealand. There are regional differences in laboratory testing methods which were originally specific to District Health Boards (DHBs), and now, to health regions under Te Whatu Ora – Health New Zealand following the dissolution of DHBs in July 2022. Diagnostic laboratories have been gradually replacing traditional culture-based methods for enteric bacteria such as *Salmonella* with culture-independent diagnostic tests (CIDT). In 2021, all community laboratories in all former DHBs except for Canterbury, South Canterbury, and West Coast had implemented screening of faecal specimens for enteric bacteria using multiplex PCR-based assays. From 2015 onward, nationally reported notification rates are a mixture of diagnoses based on PCR and non-PCR approaches. Method changes can affect notification rates. However, initial analyses comparing notification trends for bacterial infections in areas using PCR-based testing and areas yet to change to CIDT suggest the change in methodology is not causing a significant increase in reported rates of salmonellosis.

<sup>83</sup> <https://www.mpi.govt.nz/dmsdocument/1214-Non-Typhoid-Salmonellae>; accessed 1 June 2023

Diagnostic laboratories in New Zealand routinely submit all *Salmonella* isolates to the ESR ERL for further typing (methods are discussed below). All isolates are serotyped and a subset undergo antimicrobial susceptibility testing. Prior to 1 November 2019, ESR conducted phage typing for the Typhimurium and Enteritidis serotypes (as well as *S. Typhi*). After this time, phage typing was replaced with WGS for clinical isolates of *S. Typhimurium* and *S. Enteritidis*, which returns a Achtman 7-gene ST (Achtman et al. 2012). PFGE, which was previously considered the 'gold standard' for the subtyping of *Salmonella* (Wattiau et al. 2011, Besser 2015, Neoh et al. 2019), was used by ESR for salmonellosis outbreak investigations until November 2019. This was then replaced by WGS-based cluster comparisons of isolates at the SNP difference level. Compared with PFGE, this approach is not subject to interpretation error, provides a substantially higher fine typing discriminatory power for surveillance and outbreak investigations, and facilitates the improved detection of smaller and geographically widespread clusters (Chattaway et al. 2019).

### B.3.1 Serotyping

Conventional serotyping of *Salmonella* isolates was described previously and is still conducted by the ESR ERL (King et al. 2011b). For some purposes, PCR-based methods are being used to determine the serotype. For example, laboratories that test poultry samples as part of the Emergency Control Scheme, may test these samples using an *S. Enteritidis*-specific PCR; a sample positive by this PCR screen must be reported as "Presumptive *Salmonella* Enteritidis" (Ministry for Primary Industries 2022b).

Another method for *Salmonella* serotyping involves computer (*in silico*) serotyping algorithms such as SeqSero2 (Zhang et al. 2019) or SISTR (Yoshida et al. 2016). These use WGS data to predict the serotype and have been shown to have a high level of accuracy relative to phenotypic testing. For example the SISTR algorithm correctly typed 94% of isolates (Uelze et al. 2020). *In silico* approaches hold promise for replacing conventional serotyping in the future.

### B.3.2 Phage typing

Once the serotype is identified, a *Salmonella* isolate can be further subtyped by measuring susceptibility to a panel of bacteriophages (King et al. 2011b). In New Zealand, the serotypes Typhimurium and Enteritidis, and the typhoidal serotypes Typhi and Paratyphi A and B, were previously phage typed. From 1 November 2019, the ESR ERL ceased all phage typing with all subsequent isolates being typed using WGS (see below).<sup>84</sup> Phage stocks are no longer available, and the method is being phased out internationally.

However, phage typing was reimplemented by the ESR ERL, at the request of MPI and the New Zealand Ministry of Health, for a selection of *S. Enteritidis* isolates from clinical, animal and poultry environment sources collected as part of the *S. Enteritidis* 2021 outbreak response.<sup>85</sup> The process has again been discontinued.

### B.3.3 Whole genome sequencing (WGS)

From 1 November 2019, the ESR ERL carried out all *Salmonella* serotyping using WGS. Reporting now provides the serotype ST. Such discrimination is important for investigating

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<sup>84</sup> [https://www.esr.cri.nz/our-research/nga-kete/infectious-disease-intelligence/enteric-reference-testing/human-salmonella-isolates/?we\\_objectID=5083](https://www.esr.cri.nz/our-research/nga-kete/infectious-disease-intelligence/enteric-reference-testing/human-salmonella-isolates/?we_objectID=5083); accessed 2 June 2023

<sup>85</sup> <https://mpi.govt.nz/dmsdocument/49207/direct>; accessed 23 November 2022

clusters of *Salmonella* isolates to determine if they are related, such as in outbreak investigations.

Finer subtyping of isolates of the same serotype and ST is achieved through SNP analysis. This approach provides high discriminatory power for microbial fine typing, as is necessary for outbreak investigations (Chattaway et al. 2019). As part of ongoing monitoring, each week the ESR ERL conducts a full cluster comparison of SNP differences looking for signals of an emerging outbreak.

Following the introduction of WGS, *Salmonella* subsp. (I) ser. 4,5,12:i:- is now reported as monophasic *S. Typhimurium*.

There is no direct correlation between phage type and genomic SNP cluster type (or ST). A single phage type may comprise more than one SNP cluster type and are therefore not all related. Conversely, SNP clusters may comprise isolates of different phage types. This is not an error as phage type susceptibility for a given isolate is determined by its accessory genome which is not used in SNP analysis. This was seen with the poultry-associated strain *S. Enteritidis* SE\_2019\_C\_01 where four apparent phage type case clusters (DT2, DT8, DT23 and DT28) were shown genomically to cluster as a single group (Jackie Wright, ESR; pers. comm).

#### **B.4 ANTIMICROBIAL RESISTANCE OF NEW ZEALAND *SALMONELLA* ISOLATES**

For the time period considered in this report for which antimicrobial susceptibility data were available (2010 to 2019), ESR tested the antimicrobial resistance of approximately 20% of all human and non-human non-typhoidal *Salmonella* isolates received for typing.<sup>86</sup> In addition, all isolates of phage types that were internationally recognised as being multidrug-resistant were tested. These included the *S. enterica* serotype 4,[5],12:i:- and *S. Typhimurium* phage types DT12, DT104, DT120, DT193 and U302. Testing was conducted yearly for the multiresistant phage types. For the other non-typhoidal *Salmonella*, testing was conducted for the years 2010 to 2016, and was then conducted every three years; the most current report was from 2019.<sup>87,88</sup>

Resistance to the 15 antimicrobials tested and multiresistance to three or more of these is shown for the years 2010 to 2019 for human isolates in Table 17 and for non-human isolates (which included isolates from animals, food and environmental samples) in Table 18. Note that the panel and number of antimicrobials differed by testing year. For each year of testing, *Salmonella* from human sources were significantly ( $p < 0.05$ ) more resistant to at least three of the antibiotics tested than *Salmonella* from non-human sources; ampicillin was identified in each year. For example, in 2019, *Salmonella* from human sources were significantly more resistant to ampicillin, amoxicillin-clavulanate, ciprofloxacin, streptomycin and sulphonamides than *Salmonella* from non-human sources, and this was independent of a history of overseas travel.

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<sup>86</sup> Data are available from the annual reports of antimicrobial susceptibility among *Salmonella*, produced by ESR and available at: <https://www.esr.cri.nz/our-research/nga-kete/infectious-disease-intelligence/antimicrobial-resistance-amr/>; accessed 2 June 2023.

<sup>87</sup> The change in typing from phage typing to WGS impacts the priority list of isolates which are tested phenotypically for antimicrobial resistance.

<sup>88</sup> Funding for testing of non-human *Salmonella* isolates ceased at the end of 2019; only human isolates are currently being tested for antimicrobial susceptibility.

The annual percentage of non-typhoidal *Salmonella* isolates (human and non-human data combined) that were resistant to three or more antimicrobials was usually less than 6%. Between 2010 and 2019, the percentage of isolates from humans that were resistant to three or more antimicrobials was between 5.1 and 9.9 per year. For non-human isolates this range was 0.0-2.9%. When the human and non-human isolates were combined, the percentages that were fully susceptible to all tested antimicrobials each year were high: 92.0% (2010), 90.3% (2011), 88.2% (2012), 86.8% (2013), 85.5% (2014), 89.3% (2015), 90.0% (2016) and 91.0% (2019).

**Table 17. Antimicrobial resistance of a sample of New Zealand non-typhoidal *Salmonella* isolates from humans, 2010-2019.**

Antimicrobial	Percent of isolates resistant each year (n=number tested)							
	2010 (n=235)	2011 (n=222)	2012 (n=230)	2013 (n=257)	2014 (n=205)	2015 (n=235)	2016 (n=237)	2019 (n=225)
Ampicillin	7.7	10.4	8.3	10.1	9.8	10.2	5.9	6.2
Amoxicillin-clavulanate	ND <sup>3</sup>	ND	ND	ND	ND	2.6	1.3	2.7
Cefotaxime	ND	ND	ND	ND	ND	ND	ND	0.4
Ceftazidime	ND	ND	ND	ND	ND	ND	ND	0.4
Cephalothin	1.3	0.5	0.9	2.0	2.4	2.1	0.0	ND
Chloramphenicol	1.3	3.2	2.6	3.1	3.9	2.6	2.5	1.8
Ciprofloxacin <sup>1</sup>	0.4	0.5	0.0	0.0	1.0	0.0	5.9	6.7
Co-amoxiclav	0.4	0.5	0.4	0.8	1.5	ND	ND	ND
Co-trimoxazole	0.9	1.8	5.2	2.3	2.4	3.0	3.4	2.7
Gentamicin	1.3	1.4	1.7	1.2	0.5	0.9	0.4	0.9
Nalidixic acid	8.1	8.6	9.6	6.6	8.3	ND	ND	ND
Streptomycin	3.8	8.1	7.0	7.0	7.3	6.0	4.2	4.4
Sulphonamides	5.5	8.1	9.1	8.6	6.8	6.8	6.3	5.8
Tetracycline	6.0	11.3	9.1	11.3	9.3	7.7	6.8	6.2
Trimethoprim	0.9	1.8	5.2	2.3	2.4	3.0	ND	ND
Multiresistant to ≥3 antimicrobials <sup>2</sup>	5.1	9.9	9.1	9.0	7.8	7.7	5.1	6.2

Data source: <https://www.esr.cri.nz/our-research/nga-kete/infectious-disease-intelligence/antimicrobial-resistance-amr/>; accessed 2 June 2023.

ND: Not determined.

<sup>1</sup> The ciprofloxacin resistance rates for 2015 are based on ciprofloxacin disc susceptibility testing and the current CLSI breakpoints. The rates for 2016 and 2019 are based on testing with the surrogate pefloxacin disc and EUCAST breakpoints.

<sup>2</sup> For estimates of multidrug resistance, and co-trimoxazole and trimethoprim resistance, were counted as a single resistance (for years that both antibiotic susceptibilities within a pair were tested).

**Table 18. Antimicrobial resistance of a sample of New Zealand non-typhoidal *Salmonella* isolates from food, animal and environmental samples, 2010-2019.**

Antimicrobial	Percent of isolates resistant each year (n=number tested)							
	2010 (n=252)	2011 (n=284)	2012 (n=203)	2013 (n=182)	2014 (n=140)	2015 (n=120)	2016 (n=133)	2019 (n=175)
Ampicillin	0.8	1.8	2.5	0.0	2.9	0.0	0.8	0.0
Amoxicillin-clavulanate	ND <sup>3</sup>	ND	ND	ND	ND	0.0	0.8	0.0
Cefotaxime	ND	ND	ND	ND	ND	ND	ND	0.0
Ceftazidime	ND	ND	ND	ND	ND	ND	ND	0.0
Cephalothin	0.0	1.1	0.5	0.0	0.7	0.0	0.0	ND
Chloramphenicol	0.4	0.0	0.5	0.6	1.4	0.0	0.0	0.0
Ciprofloxacin <sup>1</sup>	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
Co-amoxiclav	0.4	0.0	0.0	0.0	0.0	ND	0.0	ND
Co-trimoxazole	0.4	0.4	0.0	0.0	0.7	0.0	0.8	0.6
Gentamicin	0.0	1.1	0.0	0.0	1.4	0.0	0.0	0.0
Nalidixic acid	0.0	1.1	0.5	1.1	2.9	ND	ND	ND
Streptomycin	1.6	2.8	2.0	2.2	2.1	0.8	0.8	0.6
Sulphonamides	2.0	2.5	1.5	3.3	1.4	2.5	1.5	0.6
Tetracycline	1.6	2.1	1.5	0.6	4.3	1.7	2.3	6.9
Trimethoprim	0.4	0.4	0.0	0.0	0.7	0.0	ND	ND
Multiresistant to ≥3 antimicrobials <sup>2</sup>	1.2	1.8	1.0	0.6	2.9	0.0	1.5	0.0

Data source: <https://surv.esr.cri.nz/antimicrobial/salmonella.php>; accessed 2 June 2023

ND: Not determined.

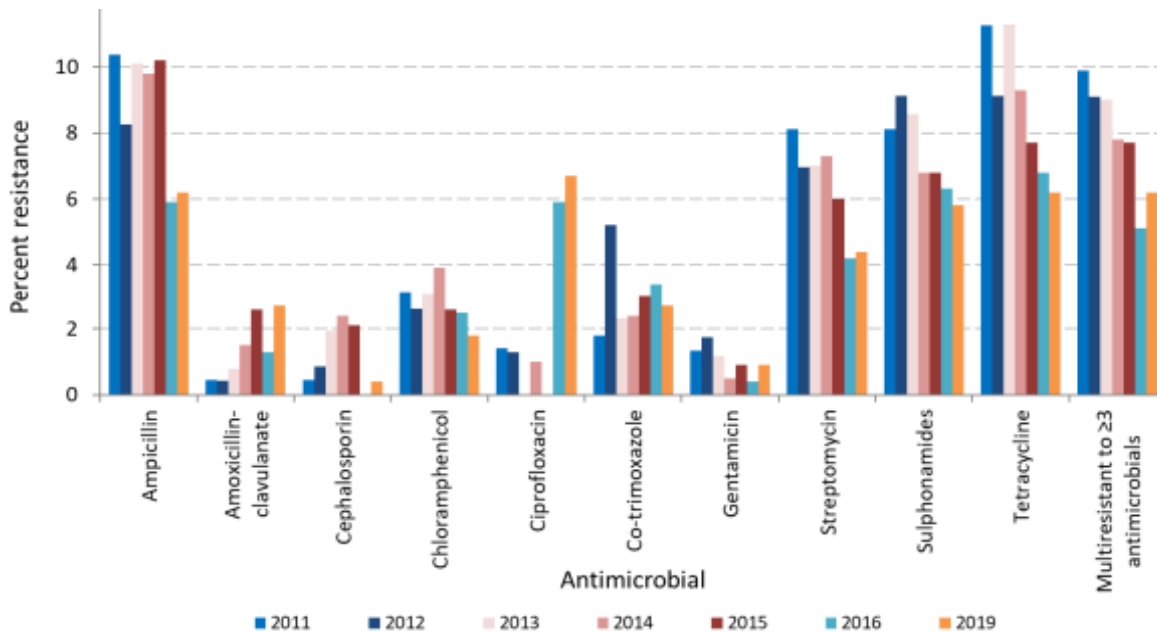
<sup>1</sup> The ciprofloxacin resistance rates for 2015 are based on ciprofloxacin disc susceptibility testing and the current CLSI breakpoints. The rates for 2016 and 2019 are based on testing with the surrogate pefloxacin disc and EUCAST breakpoints.

<sup>2</sup> For estimates of multidrug resistance, co-trimoxazole and trimethoprim resistance, were counted as a single resistance (for years that both antibiotic susceptibilities within a pair were tested).

Trends in antimicrobial resistant *Salmonella* from human cases for the years 2011 to 2019 are shown in Figure 4. As noted in the 2019 report,<sup>89</sup> there has been a significant decrease ( $p < 0.05$ ) in resistance towards ampicillin, streptomycin, sulphonamides, and tetracycline since 2011. There has been a significant increase ( $p < 0.05$ ) in resistance for amoxicillin-clavulanate and ciprofloxacin which may be related to a method change from the Clinical and Laboratory Standards Institute (CLSI) to the European Committee on Antimicrobial Susceptibility Testing (EUCAST) standard, which was introduced in 2016. The increase in ciprofloxacin resistance may be partially attributable to the use of the surrogate pefloxacin disc, which detects lower-level ciprofloxacin resistance than testing with ciprofloxacin itself.

For the time period 2010 to 2019, significantly more *Salmonella* isolates from salmonellosis cases reported to have travelled overseas were resistant to at least one antimicrobial than isolates from cases for whom no recent overseas travel was reported.

<sup>89</sup> [https://surv.esr.cri.nz/PDF\\_surveillance/Antimicrobial/SAL/SAL\\_2017-2019.pdf](https://surv.esr.cri.nz/PDF_surveillance/Antimicrobial/SAL/SAL_2017-2019.pdf), accessed 7 November 2022.



**Figure 4. Resistance among non-typhoidal *Salmonella* from human cases, 2011 to 2019. Graph reproduced from ESR (2019).<sup>89</sup>**

- The ciprofloxacin resistance rates for the years 2011 to 2015 are based on ciprofloxacin disc susceptibility testing and the current CLSI breakpoints. The rates for 2016 and 2019 are based on testing with the surrogate pefloxacin disc and EUCAST breakpoints. Testing with a pefloxacin disc is more likely to detect low-level ciprofloxacin resistance than ciprofloxacin disc susceptibility testing. This change in test procedures is likely to account for the apparent increase in ciprofloxacin resistance from 2016.
- The cephalosporin resistance rates for the years 2011 to 2016 are based on cephalothin (1st generation cephalosporin) disc susceptibility testing. The rates for 2019 are based on cefotaxime and ceftazidime (3rd generation cephalosporin) disc susceptibility testing. This change in test procedure may be responsible for the apparent decrease in cephalosporin resistance.

The prevalence and multiresistance status of all isolates belonging to internationally recognised multiresistant *S. Typhimurium* phage types during the period 2010 to 2019 is shown in Table 19. These phage types include *S. Typhimurium* phage types DT104, U302, DT12, DT120 and DT193, which are characterised by resistance to ampicillin, chloramphenicol, streptomycin, sulphonamides, and tetracycline. In addition, *S. enterica* serotype 4,[5],12:i:- (which is considered a monophasic variant of *S. Typhimurium*) is tested; isolates of which are typically multiresistant to ampicillin, streptomycin, sulphonamides and tetracycline. *S. enterica* serotype 4,[5],12:i:- was the most commonly reported each year, and isolate numbers appear to be increasing (21 in 2010; 57 in 2019 when it was the third most common serotype). The majority of isolates of this serotype were multiresistant (62% to 100% depending on the year).

**Table 19. Prevalence of known multiresistant *S. Typhimurium* phage types and the 4,[5],12:i:- serotype in New Zealand (isolates from humans, environmental sources, food and animals) for the years 2010 to 2019.<sup>1</sup>**

Type	Number of isolates of type tested multiresistant/number of isolates of type (number for which overseas travel identified) <sup>2</sup>									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
DT104	1/1	2/2 (1)	0/0	0/0	0/0	1/1	0/0	0/0	0/0	0/0
U302	0/2	1/1	1/1 (1)	0/0	1/1	0/0	0/1	0/1	1/1 (1)	0/0
DT120	1/1 (1)	3/3 (2)	2/3 (1)	0/0	1/5 (1)	0/0	1/3 (1)	3/4 (2)	1/3 (1)	1/3
DT193	0/1	0/4 (2)	0/22	1/14	3/27 (1)	7/18	0/9	3/25 (1)	3/7 (1)	5/12
DT12	0/0	0/0	0/0	0/1	0/0	0/0	0/11	0/9	0/0	2/8 (2)
4,[5],12:i:-	13/21 (7)	22/22 (11)	38/38 (12)	24/34 (19)	24/27 (22)	27/33 (23)	30/34 (20)	29/36 (19)	23/26 (18)	41/57 (21)
<i>Total</i>	15/26 (8)	28/32 (16)	41/64 (14)	25/49 (19)	29/60 (24)	35/52 (23)	31/58 (21)	35/75 (22)	28/37 (21)	49/80 (23)

<sup>1</sup> Data source: <https://www.esr.cri.nz/our-research/nga-kete/infectious-disease-intelligence/antimicrobial-resistance-amr/>; accessed 2 June 2023.

<sup>2</sup> Travel status of cases is not always reported.

## B.5 SALMONELLOSIS IN OTHER COUNTRIES

### B.5.1 Adverse health effects in other countries

Table 20 shows the reported incidence of salmonellosis in a selection of other countries. Data are also shown for the most commonly observed serotypes from clinical cases in those countries or regions.

**Table 20. Reported incidence data for notified cases of salmonellosis and commonly observed serotypes in other countries or regions, 2018-2021.**

Country	Incidence (cases/100,000)	Year	Top 3 serotypes (% of total cases where reported, or population incidence)	Reference/source
Australia <sup>1</sup>	56.3	2018	<i>S. Typhimurium</i> (32.5%), <i>S. Enteritidis</i> (6.7%), <i>S. Virchow</i> (4.6%)	Australian Department of Health and Aged Care, National Notifiable Disease Surveillance System <sup>1</sup>
	57.5	2019	<i>S. Typhimurium</i> (33.4%), <i>S. Enteritidis</i> (7.8%), <i>S. Virchow</i> (4.5%)	
	46.9	2020	<i>S. Typhimurium</i> (41.6%), <i>S. Saintpaul</i> (5.7%), <i>S. Virchow</i> (4.9%)	
	41.7	2021	<i>S. Typhimurium</i> (31.2%), <i>S. Saintpaul</i> (10.9%), <i>S. Virchow</i> (5.4%)	
Canada	19.7	2018	<i>S. Enteritidis</i> (42%), <i>S. Typhimurium</i> (8%), Heidelberg (5%)	(Government of Canada 2019, 2020)
	16.9	2019	<i>S. Enteritidis</i> (50.9%), <i>S. Typhimurium</i> (12.6%), monophasic <i>S. Typhimurium</i> (1,4, [5],12:i:-) (6.6%)	
European Union <sup>2</sup>	20.1	2018	<i>S. Enteritidis</i> (60.9%), <i>S. Typhimurium</i> (13.8%),	(European Food Safety Authority and European Centre for Disease Prevention and Control 2019)

Country	Incidence (cases/100,000)	Year	Top 3 serotypes (% of total cases where reported, or population incidence)	Reference/source
			monophasic <i>S. Typhimurium</i> (1,4, [5],12:i:-) (4.7%)	
	20.0	2019	<i>S. Enteritidis</i> (50.3%), <i>S. Typhimurium</i> (11.9%), monophasic <i>S. Typhimurium</i> (1,4, [5],12:i:-) (8.2%)	(European Food Safety Authority and European Centre for Disease Prevention and Control 2021a)
	13.7	2020	<i>S. Enteritidis</i> (48.7%), <i>S. Typhimurium</i> (12.4%), monophasic <i>S. Typhimurium</i> (1,4, [5],12:i:-) (11.1%)	(European Food Safety Authority and European Centre for Disease Prevention and Control 2021b)
	15.7	2021	<i>S. Enteritidis</i> (54.6%), <i>S. Typhimurium</i> (11.4%), monophasic <i>S. Typhimurium</i> (1,4, [5],12:i:-) (8.8%)	(European Food Safety Authority and European Centre for Disease Prevention and Control 2022)
US <sup>3</sup>	18.3	2018	<i>S. Enteritidis</i> (2.6 per 100,000 population), <i>S. Newport</i> (1.6 per 100,000 population), <i>S. Typhimurium</i> (1.5 per 100,000 population)	(Tack et al. 2019)
	17.1	2019	<i>S. Enteritidis</i> (2.6 per 100,000 population), <i>S. Newport</i> (1.4 per 100,000 population), <i>S. Typhimurium</i> (1.3 per 100,000 population)	(Tack et al. 2020)
	13.3	2020	<i>S. Enteritidis</i> (1.6 per 100,000 population), <i>S. Newport</i> (1.5 per 100,000 population), <i>S. Javiana</i> (1.0 per 100,000 population)	(Ray et al. 2021)
	14.2	2021	<i>S. Enteritidis</i> (17%), <i>S. Newport</i> (11%), <i>S. Typhimurium</i> (9%)	(Collins et al. 2022)
New Zealand	22.5	2018	<i>S. Typhimurium</i> (34.0%), <i>S. Enteritidis</i> (12.8%), <i>S. Bovismorbificans</i> (8.1%)	Table 6
	24.2	2019	<i>S. Typhimurium</i> (39.1%), <i>S. Enteritidis</i> (15.8%), <i>S. Bovismorbificans</i> (4.7%)	
	13.9	2020	<i>S. Typhimurium</i> (49.7%), <i>S. Enteritidis</i> (10.7%), <i>S. Bovismorbificans</i> (8.6%)	
	13.9	2021	<i>Typhimurium</i> (47.6%), <i>Enteritidis</i> (19.5%), <i>Bovismorbificans</i> (7.4%)	

<sup>1</sup> Australian data were extracted from the websites: <https://nindss.health.gov.au/pbi-dashboard/> (salmonellosis yearly incidence) and <https://www.health.gov.au/resources/publications/national-notifiable-diseases-surveillance-system-nndss-public-dataset-salmonella?language=en> (*Salmonella* serotypes). Data from NNDSS was presented as total cases; the rate was calculated from the Australian Bureau of Statistics; <https://www.abs.gov.au/>

<sup>2</sup> Includes data from 27 countries, not including data from the UK.

<sup>3</sup> FoodNet surveillance data are from 10 US states, including ~15% of the US population.

### **B.5.2 Risk factor studies from other countries**

The potential for starlings (*Sturnus vulgaris*) to contribute to *Salmonella* contamination in a concentrated cattle feeding operation was examined at 10 facilities in Texas, US (Carlson et al. 2011). Starlings, cattle feed, cattle water and cattle faeces were sampled and analysed for *S. enterica*. *Salmonella* was detected in 2/81 (2.5%) of starling gastrointestinal tract samples, 16/191 (8.4%) cattle feed samples, 23/169 (13.6%) water trough samples and 4/61 (6.5%) cattle faecal samples. A generalised linear mixed logistic regression model was used to examine the contribution of starlings, cattle stocking, facility management and environmental variables to *Salmonella* transmission. *Salmonella* contamination of both feed and water troughs was significant, associated with starling numbers, but cattle faecal *Salmonella* shedding was not.

A study examined associations between pig feed mill ( $n = 6$ ) characteristics (number of suppliers, production volume, feed types, proportion of in-state suppliers and mill age) and *Salmonella* prevalence in environmental swabs (Magossi et al. 2020). No statistically significant odds ratios were determined for any risk factors.

The Canadian Food Inspection Agency are developing an Establishment-based Risk Assessment model for livestock feed mills to assist in the allocation of inspection resources based on feed safety risk (Rhouma et al. 2021). As part of this process, a literature review and expert consultation was carried out to identify animal health and food safety related risk factors. There were 34 risk factors identified and these were grouped into inherent (4), mitigation (10) and compliance (20) risk factors. Inherent risk factors included: annual distribution volume, type of facility (presence of single or multiple species being processed on-site), manufacturing practices (single/multiple species, open equipment systems, manufacturing mash or premix feed) and at risk feed ingredients (use of prohibited materials, use of animal products and by-products, importation of feed ingredients by a third party, mixing domestic and imported ingredients, importing bulk ingredients and factors related to medicated feed. This exercise was not specific to any particular contaminant such as *Salmonella*.

# APPENDIX C: REGULATORY CONTROL MEASURES IN OTHER COUNTRIES

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## C.1 CONTROL MEASURES IN NEW ZEALAND

Areas of the *Manufacture of Animal Feeds in New Zealand - Code of Practice* (New Zealand Feed Manufacturers Association 2023b) pertaining to the control and monitoring of *Salmonella*, are detailed below.

### Feed ingredients

The purchasing specifications in relation to *Salmonella* depend on the feed ingredient and destination feed type. The Code specifies that:

- “Purchasing specifications for all animal products used as ingredients in feed manufacture should require that *Salmonella* is absent in the product.
- Absence of *Salmonella* should be included in the purchasing specifications for all other ingredients, local or imported.
- It is important to consider the risk posed by the potential presence of *Salmonella* in feed ingredients as part of the *Salmonella* control plan for the mill. For example, purchasing of an ingredient known to be positive for *Salmonella* may be an option if appropriate control measures (i.e., heat treatment) are in place. However, consideration would need to be given to the prevention of cross-contamination during storage and prior to critical control points.
- Procedures must be in place for minimising the risk of *Salmonella* contamination (and growth) where dry ingredients are received with higher moisture content than that specified in the purchasing specifications.
- Supplies of animal by-products from new sources must not be used until the *Salmonella* status has been properly determined.
- In the event of a positive *Salmonella* result, a response procedure must be in place to minimise the possibility of cross contamination of ingredients and to prevent a re-occurrence.”

### *Salmonella*-specific requirements during milling

- “It is recognised that for the control and elimination of *Salmonella* in the feed chain effective strategies need to be employed across the whole spectrum from feed to processing of the animal product. Feed is a vital step in reducing and eliminating a likely source of *Salmonella* contamination.
- *Salmonella* control can be achieved by various processing techniques and the choice of the technique employed depends on many factors, such as:
  - the end-user/consumer, i.e., domestic pet or production animal for human consumption,
  - susceptibility of a particular animal species to specific *Salmonella*,
  - age of the animal,
  - other food chain interventions which can be employed later in the process, i.e., vaccination,
  - the status of *Salmonella* as a food borne risk to humans in a particular production animal species,
  - customer requirements,

- *Salmonella* risk of ingredients,
- equipment in a mill,
- treatments at slaughter/processing of animal ingredient.
- It may be appropriate that certain feeds for certain species do not require a *Salmonella* treatment control step during manufacture.
- For other species, the manufacturer or customer needs to determine what the microbial specifications are and what processing treatments are appropriate.”

## C.2 CONTROL MEASURES IN OTHER COUNTRIES

### C.2.1 Australia

Over 90% of Australian compound feed manufacturers, in terms of proportion of total animal feed made, are members of the Stock Feed Manufacturers’ Council of Australia.<sup>90</sup> They produce over 5,500,000 tonnes of feed annually, from 180 manufacturing sites. Members must also comply with the FeedSafe® quality assurance programme.<sup>91</sup> The FeedSafe® standards are defined in the Australian Code of Good Manufacturing Practice for the Feed Milling Industry (2009). Part of the programme involves compliance with strict biosecurity practices for feed mills (Stock Feed Manufacturers’ Council of Australia 2021). An important component of this program is monitoring for *Salmonella* contamination in the feed mill, milling equipment, raw materials and finished feeds so that targeted risk management such as recalls can be implemented. Other control procedures with respect to *Salmonella* could include:

- Higher manufacturing temperatures for certain feeds,
- Particularly high cleanliness standards for the post-pelleting cooling areas because there are no further antibacterial processes applied following pelleting.

### C.2.2 Canada

Animal feed produced, imported into, or exported from Canada is regulated by the *Feeds Act*.<sup>92</sup> The Canadian Government has provided regulatory guidance for the prevention, control and mitigation of *Salmonella* in livestock feeds.<sup>93</sup>

Requirements for industry include a preventative control plan or HACCP-based programme. With respect to *Salmonella*, this includes:

- The outcomes from the establishment's hazard identification and analysis;
- Where *Salmonella* is identified as a hazard, a description of the control measures implemented to control *Salmonella* and evidence that the control measures are effective (for example, scientific literature, best practices, etc.); and
- Procedures for verifying that the implementation of the plan results in compliance (that is, no *Salmonella* detected). This might include a *Salmonella* monitoring sampling program to demonstrate compliance. Although internal monitoring for *Salmonella* is encouraged, it is not mandatory.

If *Salmonella* is detected, producers must act to prevent the entry of *Salmonella* into the food and feed chain. Actions include product control to prevent distribution of the contaminated feed and prevent further contamination, a risk assessment (with particular attention to the

<sup>90</sup> <https://www.sfmca.com.au/aboutassociation>; accessed 8 June 2023

<sup>91</sup> <https://www.feedsafe.com.au/>; accessed 8 June 2023

<sup>92</sup> <https://laws-lois.justice.gc.ca/PDF/F-9.pdf>; accessed 8 June 2023

<sup>93</sup> <https://inspection.canada.ca/animal-health/livestock-feeds/regulatory-guidance/rg-11/eng/1675712687883/1675712688486>; accessed 8 June 2023

serotype and potential risk), treatment of the feed if possible (re-rendering if it is rendered product), re-directing to an alternate, non-feed usage, or safe disposal.

Livestock feed company compliance with the regulatory requirements is monitored by the Canadian Food Inspection Agency, who carry out the following *Salmonella* feed sampling programs:

- the "*Salmonella* monitoring sampling program" randomly samples livestock feeds from commercial feed mills, rendering establishments, and single ingredient feed manufacturers; and
- the "*Salmonella* directed sampling program" is focused on establishments that have an unacceptable compliance history with respect to *Salmonella* or have tested positive for a *Salmonella* serotype that poses a high risk to humans and animals (which includes the serotypes Typhimurium, Enteritidis, Heidelberg, Newport, Thompson, Hadar, Infantis and I 4,[5],12:i.).

The types of materials that are more likely to be sampled are those that have previously been found to have a higher *Salmonella* prevalence, including: rendered meats, oilseed meals, grains, recycled food products and mash feeds. If *Salmonella* is detected in feed samples, regardless of the serotype, the sampled lot is considered non-compliant and a response by the producer is required (for example, development and implementation of a corrective action plan). In addition to verifying that industry is meeting their regulatory obligations with respect to *Salmonella*, the monitoring sampling program is used for routine surveillance purposes.

### C.2.3 Europe

The legal basis for the control of *Salmonella* in animal feed in Europe is laid down in the following legislations:

- Commission Regulation EC 183/2005 provides general requirements for feed hygiene involving implementing, maintaining and documenting procedures based on HACCP principles. There are also conditions for feed traceability, and for registration and approval of manufacturers.<sup>94</sup> There are separate and parallel regulations for England, Scotland, Wales and Northern Ireland.
- Regulation EC 2003/99<sup>95</sup> addresses the monitoring of zoonoses and zoonotic agents, including *Salmonella* in animal feed.
- Regulation EC No. 2160/2003<sup>96</sup> ensures that measures are taken to detect and control *Salmonella* and other zoonotic agents at all relevant stages of production, processing and distribution, particularly at the level of primary production, in order to reduce their prevalence and the risk they pose to public health.
- The Animal By-Products Regulations 2011 No.881 (UK)<sup>97</sup>.

Examples of governmental and industry Codes of Practice and HACCP programmes that have been developed in Europe for the monitoring and control of *Salmonella* in animal feed, include:

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<sup>94</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02005R0183-20220128>; accessed 8 June 2023

<sup>95</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02003L0099-20130701>; accessed 8 June 2023

<sup>96</sup> <https://www.legislation.gov.uk/eur/2003/2160/contents>; accessed 12 June 2023

<sup>97</sup> [https://www.legislation.gov.uk/ukxi/2011/881/pdfs/ukxi\\_20110881\\_en.pdf](https://www.legislation.gov.uk/ukxi/2011/881/pdfs/ukxi_20110881_en.pdf); accessed 12 July 2023

- DEFRA Codes of Practice for the control of *Salmonella* during the production, storage and transport of compound feeds, premixtures, feed materials and feed additives (UK).<sup>98</sup> The document also specifies monitoring for the presence of *Salmonella* in the plant environment and equipment (including vehicles), incoming and outgoing product.
- Agricultural Industries Confederation Universal Feed Assurance Scheme, which accounts for >95% of the commercially produced compound feed in the UK and Ireland.<sup>99</sup>
- European Feed Manufacturers Guide of a common set of principles for the management of *Salmonella* risk in the feed chain.<sup>100</sup> The document specifies that a monitoring plan for *Salmonella* should be established by feed compounders for incoming materials, focusing on those of higher risk, as well as after critical *Salmonella* control points. The objective is to minimise contamination of all *Salmonella* serotypes along the feed supply chain. Further serotyping might be performed, for example, for traceability purposes, or with a special focus on some pathogenic *Salmonella* serotypes such as *S. Enteritidis*, *S. Typhimurium*, *S. Hadar*, *S. Virchow* and *S. Infantis*.
- Product Board Animal Feed GMP+ (the Netherlands) specifies that the rejection limits for *Salmonella* in all livestock feeds is 0% detection, or absence in 25 g.<sup>101</sup>

#### C.2.4 US

The US Rule 80 FR 56337 *Current Good Manufacturing Practice, Hazard Analysis, and Risk-Based Preventive Controls for Food for Animals* provided by the US Health and Human Services Department and the US FDA has been effective since 16 November 2015.<sup>102</sup> Specifically, the rule created current good manufacturing practice regulations for the manufacturing, processing, packing, and holding of animal feed. It also includes preventive control provisions intended to implement section 103 of the FDA Food Safety Modernization Act for animal food.<sup>103</sup> The preventive controls include requirements for facilities to maintain a food safety plan, perform a hazard analysis (such as for pathogens including *Salmonella*), and institute preventive controls for the mitigation of those hazards. Facilities are required to monitor their controls, verify that they were effective, take any appropriate corrective actions, and maintain records documenting these actions.

<sup>98</sup> <https://www.agindustries.org.uk/resource/defra-salmonella-feed-code-of-practice.html>; accessed 12 June 2023

<sup>99</sup> <https://www.agindustries.org.uk/sectors/trade-assurance-schemes/ufas-universal-feed-assurance-scheme.html>; accessed 12 June 2023

<sup>100</sup> [https://fefac.eu/wp-content/uploads/2022/01/10\\_PR\\_10\\_E.pdf](https://fefac.eu/wp-content/uploads/2022/01/10_PR_10_E.pdf); accessed 12 June 2023

<sup>101</sup> <https://www.gmpplus.org/media/krqjkz5h/gmp-ba1-en-20191217.pdf>; accessed 13 June 2023

<sup>102</sup> <https://www.ecfr.gov/current/title-21/chapter-I/subchapter-E/part-507>; accessed 13 June 2023

<sup>103</sup> <https://www.fda.gov/food/food-safety-modernization-act-fsma/full-text-food-safety-modernization-act-fsma#SEC103>; accessed 13 June 2023